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SECURING U.S. LEADERSHIP IN EMERGING COMPUTE TECHNOLOGIES

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED SEVENTEENTH CONGRESS

SECOND SESSION

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED SEVENTEENTH CONGRESS

SECOND SESSION

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SECURING U.S. LEADERSHIP IN EMERGING COMPUTE TECHNOLOGIES

THURSDAY, SEPTEMBER 29, 2022

U.S. SENATE
COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION,
Washington, DC.

The Committee met, pursuant to notice, at 10:04 a.m., in room SR–253, Russell Senate Office Building, Hon. Maria Cantwell, Chair of the Committee, presiding.

Present: Senators Cantwell [presiding], Klobuchar, Blumenthal, Peters, Baldwin, Rosen, Luján, Hickenlooper, Wicker, Fischer, Blackburn, Young, and Lummis.

OPENING STATEMENT OF HON. MARIA CANTWELL, U.S. SENATOR FROM WASHINGTON

The CHAIR. Good morning. The Senate Committee on Commerce, Science, and Transportation will come to order. This morning, we will be having a hearing on securing U.S. leadership in emerging compute technologies, or in other words, what do we do with the CHIPS and Science money and the actual appropriations that we need to get to keep our competitive edge in compute science.

So very distinguished panel here this morning to discuss this very important issue. I would like to welcome all of them. In August, the President signed the bipartisan CHIPS and Science Act into law with historic commitment to U.S. technology leadership.

This hearing is about ensuring what we do as a nation to keep that commitment by building the workforce needed to stay competitive in the most leading edge and consequential computational disciplines.

Leading the world in computation grows the economy, creates new jobs, and keeps America safe. Computing helped put Americans on the Moon, develop faster and stealthier planes, better weather forecasting artificial intelligence for precision agriculture.

That is why the CHIPS and Science Act was so focused on building America's computing capabilities. America knows that the new law invested more than $50 billion into chip manufacturing, and they already are seeing results.

The groundbreaking announcements in Ohio, Idaho, North Carolina, and even in my home state of Washington have all put manufacturing resurgence to a point of gaining steam. But just as important in the law is the focus on research and workforce development in ten key technology areas. Four of these areas, artificial intelligence, semiconductors, quantum science, and distributed ledger technologies deal with improving computation.

Job openings in these areas are soaring, but the number of workers definitely is not keeping pace. It is a crisis. That is why the CHIPS and Science Act authorized $13 billion for STEM education, including funds for nearly 40,000 scholarships, fellowships, and traineeships. That is why it has money for faculty hiring and training.

And make no mistake, America's workforce shortages are serious. And failing to make these investments and failing to retain the talent from around the world is not an option. With six decades of AI development, computers now operate vehicles, translate languages, create art, help on the factory floor, and most of you know in this room are probably hearing AI technologies right now.

But AI doesn't work alone, and it is far from perfect. It must be trained by humans and must often be partnered with the human in doing the work, and that means we need a generation of AI literate workers. A recent Georgetown study supported that we will add 1 million AI jobs between 2019 and 2029.

AI requires vast amounts of information and excellent data retrieval capabilities, which is one of the promises of distributed ledger technologies. But in the computation—but in the computer science foundational discipline for this technology, universities are turning away students because the supply of teachers isn't keeping up with demand.

The country that combines the power of quantum computing with artificial intelligence could make an insurmountable leap forward in technology and rewrite the rules of the road for cybersecurity, for creating medical innovations and saving thousands of lives, and developing battlefield technologies.

The nation faces a shortage of a quantum talent, with fewer than 5 percent of U.S. PhDs in relevant fields focusing on quantum science. So the stakes are high. International competition is mounting. Funding for CHIPS and Science must not stop with the appropriations for chip manufacturing.

America needs access to better chips, but it also needs the research and workforce to put those chips to use. So that is why I am proud to have with us one of our witnesses, Dr. Albritton, who we will hear from shortly. Washington is a leader in emerging computational technology.

Seattle has the Nation's third largest AI workforce. The University of Washington is one of the Nation's top institutions for AI. In the Spokane region, home to more than 7,000 farms and ranches, WSU leads the Institute on Agriculture AI with a focus on AI enabled workforce, and companies like Amazon, Microsoft, T-Mobile and Starbucks are applying distributed ledger technologies to telecommunications and supply chain.

And we are building the quantum workforce through the efforts like the University of Washington's Quantum X Institute, which is creating a graduate certificate program in quantum science. With the CHIPS and Science Act, I hope to see Washington continue to grow this leadership and developing a workforce.

Each of these technologies will face challenges, but if America is to lead, we need to continue to lead in talent. So I look forward to hearing from the distinguished panel today, and I will now turn to the Ranking Member for his opening statement.

STATEMENT OF HON. ROGER WICKER, U.S. SENATOR FROM MISSISSIPPI

Senator WICKER. Thank you, Madam Chair. And let me say of all the legislation that you and I have worked shoulder to shoulder on, I can't think of anything more significant for the future of our country, and not only our economy but also our national security, than the CHIPS and Science Act.

And so thank you so much for being my partner in that regard and for persuading the House and Senate to include the very significant additions that we made. Today's hearing on securing U.S. leadership in emerging technologies could not be more timely.

The recently enacted CHIPS and Science Act provided critical investments and policy tools to advance American innovation in key technologies, including, as the chair said, quantum computing, artificial intelligence, and blockchain.

The development of these emerging technologies is important but also poses important questions for policymakers involving security, privacy, and other impacts on society. Today's witnesses play key roles in technology development and innovation.

The Chair is proud of witnesses from the state of Washington, and I am similarly delighted that Dr. Henry Jones is here, the Director of Research and Development and Scientific Entrepreneurship at the University of Southern Mississippi, and Mr. Trey Breckenridge, the Director of High Performance Computing at Mississippi State University.

I look forward to hearing their thoughts on spreading the geography of innovation when it comes to innovation. The—one of the most significant provisions that we were able to add, Madam Chair, is to spread the geography and avoid overreliance on a handful of States and big universities. American leadership requires that we take advantage of the talent, expertise, and capabilities found throughout America.

In that vein, I would appreciate eyewitnesses? perspectives on where the United States ranks regarding the development of these emerging technologies, particularly as compared to China, and what more should be done to secure a preeminent position. China and other nations are increasingly dominant in technology innovation, posing a massive threat not only to our economy, but, as I said, to national security.

There is no more important competition than the one for technological supremacy between the United States and China. Congress has recognized this fact and has taken the first step by passing the CHIPS and Science Act, which would position the United States to be a global leader once again.

This law establishes a new Directorate for Technology, Innovation and Partnerships at the NSF to accelerate the process of translating basic research into technology development for commercial use and making America more competitive globally. Geographic diversity is a vital—is vital to American innovation and enlisting the talent and expertise of STEM researchers nationwide is an important priority.

In the CHIPS and Science Act, the law guarantees that EPSCoR, a program designed to stimulate competitive research in 25 predominantly rural states, will receive 20 percent of all R&D funding from the NSF, up from the current 13 percent. This will go a long way toward developing—toward leveraging the whole of America's technological expertise in this global contest.

Make no mistake, ensuring that America leads the world in tech is good for our economy and national security, and it is also good for the cause of freedom, stability, openness, and our democratic values around the world. With the right vision and priorities, we in Congress can make sure the 21st century is another American century. So I look forward to hearing from our distinguished witnesses, and I thank the Chair.

The CHAIR. Thank you, Senator Wicker. And thank you for your leadership on the EPSCoR issue, particularly. It was something that we spent a lot of time on. And I firmly believe I saw this morning that Steve Case has a book, "The Rise of the Rest."

And I think with the Intel investment in Ohio and what we are doing, I don't want to steal Dr. Albritton's testimony, but I think she is going to tell us she is originally from Louisiana, and I think that is the point, that we have talent all throughout the United States of America and what do we do to better unleash that.

And hopefully today's hearing will be a very poignant point forward to our appropriators that we have to get the rest of this right. But now I am going to——

Senator WICKER. Madam Chair, if because of your statement, sales of Mr. Case's book shoot through the roof, the Case family will be able to have Christmas this year.

The CHAIR. I am pretty sure they can anyway, but I probably would have had him come in—this is a hard subject because it is not hard, it is distributed generation. But when we were definitely in the negotiations, we spent a lot of time on this for a lot of different reasons. And some institutions who are already making R&D contributions, it is hard.

But I think we got it right and I think that we are going to move forward, and I think we are going to see the dividend of that. So thank you for your leadership. Senator Hickenlooper from the Subcommittee is going to make an opening statement.

STATEMENT OF HON. JOHN HICKENLOOPER, U.S. SENATOR FROM COLORADO

Senator HICKENLOOPER. Thank you, Madam Chair. I thank all of you for schlepping out here and spending the better part of a day with us. It is exciting to be part of such an impressive group. The recently passed CHIPS and Science Act really is a massive investment in our country's future.

I was proud to be a conferee on the bipartisan Innovation and Competition Conference, part of that. The drive that R&D receives is what helps our economy grow, it improves our public health, it strengthens our national defense. It affects us in almost every manner possibly.

When I was a kid, there was a movie called, Being There, written by a guy named Jerzy Kosinski who, Chance the gardener, turned out to be an expert in the economy. And basically he was rather simple minded. But his metaphor he used for everything was back to the garden, whether it had the nutrients.

The garden as an ecosystem. Well, I think what the CHIPS bill does is invest $200 billion into our scientific ecosystem. And just like the garden in Being There, the nutrients and the diversity of what is in that ecosystem is crucial to its success. We need to grow and diversify our skilled workforce, making sure we have pathways other than the traditional 4-year degree.

We have to increase manufacturing and innovation in every part of the nation, as Madam Chair was just saying. Steve Case and others have begun that process of looking into rural areas all across America and finding out how do we stimulate innovation everywhere. We are in a fierce rivalry, a fierce competition with China, around a number of countries, and we need everybody on deck.

We are thrilled to see last week that the Senate confirmed Dr. Prabhakar to head the White House Office of Science and Technology Policy. She is going to play a pivotal role in implementing CHIPS and Science by developing the National Science and Technology Strategy, and perhaps more importantly, coordinating the efforts across all the Federal agencies and with the different offices of the White House.

I think what we are doing here today is really discussing the future of computing to a large extent. We have three focuses today that showcase what we can already achieve, but also what we will be able to do in the near future. One, artificial intelligence, AI, has the power to automate complex processes and improve our efficiency in every sector of our economy.

As more and more businesses incorporate AI into their operations, we need to accelerate that integration. We must ensure that these systems are transparent, and as much as possible, free from bias.

I applaud the National AI Initiative Office's efforts to gather broad public input and to convene experts from Government, academia, and industry to make sure we get off on the right path. Second, quantum information science, UIS, is an advanced field, which I am proud to say, deep history in Colorado. It will transform the future of computing and let us run simulations with staggering speed.

Colorado's own ColdQuanta, Dr. Sutor is here, is on the cutting edge, some would say the bleeding edge, of this computing revolution. NIST has a partnership with CU Boulder to advance quantum technologies through their joint institute, the JILA, including world record accurate atomic clocks.

Further partnership with CU Boulder, NIST, and front range companies has joined together to form the CUBIT, I did not come up with that acronym, CUBIT initiative, which is going to help accelerate our growing quantum ecosystem in Colorado, and I think in a similar way, we will accelerate ecosystems around the country.

Third, after quantum information science's distributed ledger technology, DLT, often implemented as blockchains, is more popularly known as blockchains, can improve security of financial transactions, support innovations and data privacy. All kinds of implementations, health care just being one.

A major DLT innovation hub is located in Wyoming, the home of space and science subcommittee's Ranking Member, Senator

Lummis. Today, I look forward to discussing important topics for all these technologies. They are so important to Colorado and to the Nation.

Which barriers should we break down to make sure that we do grow a skilled STEM workforce in all these fields? What are the guardrails we need to make sure we create to ensure these technologies are developed transparently, used ethically, and benefiting everyday lives of all Americans.

With the springboard created by the historic CHIPS and Science Act, how do we ensure that the United States remains the global gold standard for innovation in each of these fields? So I thank all of you for joining us in delving into these issues and I return—yield to the Chair.

The CHAIR. Thank you. I don't see Senator Lummis here or online, but if she does arrive and wants to give us opening statement as the Ranking Member of the Subcommittee, we will definitely look forward to hearing her comments. We will now turn to the witnesses. I want to welcome Dr. Nancy Albritton, Dean of the College of Engineering at the University of Washington, the Frank and Julie Jungers Dean.

I also want to welcome Dr. Jack Clark, Co-Founder of Anthropic; Mr. William Breckenridge III, Director of High Performance Computing and High Performance Computing Collaborative, Mississippi State University; Mr. Steve Lupien is joining us remotely. He is the Director of the Center for Blockchain and Digital Initiatives at the University of Wyoming College of Business.

Dr. Bob—is at Suter? Sutor—Dr. Bob Sutor, Vice President, Corporate Development of ColdQuanta; and Dr. Henry Jones, Director of Research and Development in Scientific Entrepreneurship, University of Southern Mississippi. So welcome to all of you. We will start with you, Dean Albritton.

STATEMENT OF NANCY ALBRITTON, M.D., PH.D., FRANK AND JULIE JUNGERS DEAN COLLEGE OF ENGINEERING DEAN, UNIVERSITY OF WASHINGTON

Dr. ALBRITTON. Good morning, Chairman Cantwell and Ranking Member Wicker, and distinguished members of the Committee. Thank you, Senator Cantwell, my Senator, for the opportunity to testify about the value and continued importance of our Nation investing in emerging computing technologies.

As noted, I am the Dean of the University of Washington College of Engineering, and the three technologies the Committee is focusing on today are areas where the University of Washington is making significant contributions. Indeed, our faculty lead multiple large, multi-institutional national science foundation awards to advance the potential of AI, machine learning, and data science, all while training the next generation of workers and innovators.

As we have already noted, Congress took a bold step with the CHIPS and Science Act. I am encouraged by this step. A sustained Federal investment in these programs is essential for our Nation to maintain its leadership on this fierce global landscape. But it is also important to leverage collaborative opportunities between Government, academia, and industry, and to build a workforce that reflects the rich diversity of our Nation.

This morning, I will focus my comments on the impact of investment in quantum information science. Starting with an example and its promise. As we all know, Hurricane Ian has made landfall in our Southern States, and as noted, I am a native of Louisiana. I keenly understand the toll that hurricanes have on a community and also the hardship of rebuilding.

Thankfully, though, forecasting models developed by NOAA, NASA, and the Pacific Northwest National Laboratory help us predict the path and intensity of these hurricanes. It is a tremendous improvement from my childhood, but just imagine if we could prepare for storms with a much higher degree of certainty.

Theoretically, a full scale quantum computer can weather—perform weather forecasting with high accuracy by handling vast amounts of data in seconds, saving lives and reducing property damage. In the 1980s, classical computing and personal computers changed the world. But now, advances in quantum information science promise major breakthroughs in communications, computing, and simulation.

Just as quantum science has enabled groundbreaking technologies such as GPS, MRI, lasers for health care applications, the realization of quantum information science will fundamentally change the way that we live and work. But now is the time to accelerate Federal investment to maintain a competitive edge.

Across the globe, growing numbers of universities, including the University of Washington, have established major quantum information programs, and the competition for students, researchers, faculty, and funding is intense, as is industry hiring. The new quantum information initiatives in the U.S. and around the world all have the same goal, not to miss this window to lead in this area.

But no country is better positioned to emerge in the top cohort than the U.S. is with its partnerships between academia, Government, and industry. At the University of Washington, though, the lack of critical quantum information science capabilities, particularly those associated with the large cost of implementation and maintenance, hampers our impact in this growing field.

Another challenge to industry growth is the shortage of equipped and diverse workforce. It is already difficult to fill skilled STEM job openings, and as quantum computing investments grow, competition for skilled worker intensifies and is an unsustainable demand.

At the University of Washington alone, student demand far exceeds capacity and most of our STEM programs, forcing us to turn away excellent students when our Nation demands a skilled workforce.

America's research universities stand ready to partner with you to provide leadership, research, and workforce education. I ask that you continue to sustain and increase Federal funding, particularly in those science agencies that will enable us to remain a global quantum information leader.

But more specifically, increase Federal investment in workforce development and education, and accessible quantum testbeds and quantum cloud computing, and high risk engineering and science research and more fundamental quantum information research, but also an investment in technology policy will be particularly impactful.

Thank you for your time and consideration. I welcome your questions.

[The prepared statement of Dr. Albritton follows:]

PREPARED STATEMENT OF NANCY ALBRITTON, M.D., PH.D., FRANK AND JULIE JUNGERS DEAN COLLEGE OF ENGINEERING DEAN, UNIVERSITY OF WASHINGTON

Good morning, Chairman Cantwell and Ranking Member Wicker, and distinguished Members of the Committee. Thank you, Senator Cantwell, my Senator, for the opportunity to testify about the value and continued importance of our Nation investing in emerging computing technologies. I am the Dean of the University of Washington (UW) College of Engineering, and the three technologies the committee is focusing on today—artificial intelligence (AI), quantum information science (QIS), and distributed ledger technologies (DLT)—are areas where the University of Washington is making significant contributions and leading nationally and internationally to develop and discover the potential of these fields while training the next generation of workers and innovators.

Earlier this year Congress took a bold step to ensure that the United States is equipped to be a global leader in science and innovation with the passing of the CHIPS and Science Act. As you know, this legislation is designed to revitalize American science and innovation, build a strong and diverse STEM workforce, create solutions for the climate crisis, and support American manufacturing. As a leader in academia, I am encouraged by this critical Federal funding, and I am here today to urge you to continue to invest in our Federal science agencies and initiatives empowered by CHIPS. Sustained Federal investment in these programs are essential for our Nation to remain a leader in a fierce global landscape, to leverage opportunities for collaboration between government, academic, and business sectors, and to build a workforce that reflects the rich diversity of our Nation.

The University of Washington has significant expertise in the three areas that the committee is focusing on today. UW faculty serve as PIs on multiple large, multi-institution NSF awards in artificial intelligence, machine learning, and data science, including the Institute for Foundations in Data Science, the Institute for Foundations in Machine Learning, and the AI Institute for Dynamic Systems. However, this morning I will focus my comments on the impact of investing in quantum information science and I'll start with an example of its promise. As I write, Hurricane Ian is strengthening before making landfall in our southern states and coastlines, with the potential to shatter communities. As a native of Louisiana, I keenly understand the toll that a destructive hurricane can have on a community and the hardship of rebuilding. Thankfully, forecasting models help us predict the path and intensity of hurricanes. Large supercomputers and artificial intelligence already aid forecasting, such as models developed by NOAA, NASA and the Pacific Northwest National Laboratory (PNNL) that can predict when hurricanes will rapidly intensify. It is a tremendous improvement from when I was growing up, but we can and should do more. However, to achieve greater accuracy in weather forecasting, more computational power is needed.

Theoretically, a full-scale quantum computer can improve weather forecasting methods by handling huge amounts of data (terabytes per second) containing many variables and optimizing complex algorithms, and can do so in seconds. With quantum computing, we will be able to prepare for these storms with a much higher level of certainty, potentially saving lives and reducing property damage.

Our society stands on the brink of a major revolution driven by quantum information science with boundless potential to fundamentally change the way we live and work. Quantum information science uses quantum effects to acquire, transmit, and process information. Quantum science has already enabled us to better understand nature and advance groundbreaking technologies like GPS, MRI scans, and lasers for healthcare applications such as eye surgery and joint surgery.

Like the 1980s when classical computing and the personal computer changed the world, recent advances in quantum information science promise major breakthroughs in communications, computing, and simulation. Industry and governments around the world are investing heavily in quantum information science, recognizing its potential and poising to capitalize on it. As the U.S. aims to be a scientific leader of the coming quantum information age, now is the time to accelerate Federal investment, as outlined by CHIPS, so our Nation is a global leader in this field.

Currently, there are growing numbers of universities with established major quantum information programs in the world, and the University of Washington is proud to be one such program with robust partnerships with industry including Microsoft, Boeing, Google, and Amazon, and with the Pacific Northwest National Laboratory (PNNL). Internationally, quantum information programs are underway in Sweden (WACQT), the Netherlands (Quantum Delta), Japan (Moonshot), Israel (Israel National Quantum Initiative), and the U.K. (UKNQTP). Germany, France, Austria, and Canada are also substantially investing in this area. China is making massive investments in quantum computing, and quantum technology more broadly, making it certain that they will emerge as a leader in this area in the next decade. Worldwide, the competition for top students, researchers, faculty, and funding is fierce, as is hiring by companies. The new quantum information initiatives in the U.S. and around the world have the same goal: not to miss the window to lead in this area. No country is better positioned to emerge in the top cohort than the U.S. in partnership with academia, government, and industry.

Investment in America's leading research universities will allow talented faculty and students to further innovative science that will elevate the U.S. as a global destination for knowledge and discovery in quantum information sciences. These foundational investments will influence economic and national security, prepare U.S. students for jobs with quantum information technology, enhance STEM education at all levels, and accelerate exploration of quantum information frontiers, all while expanding and diversifying the talent pool for the industries of the future in Washington state and across the Nation.

For example, the Washington Quantum Technologies, Teaching and Testbed Laboratory (QT3) provides a regional resource for hands-on quantum technology training to the next generation of quantum scientists and engineers and state-of-the art quantum device characterization research tools in a publicly accessible user facility.

In this second quantum revolution, society will leverage the quantum-mechanical properties of light and matter to enable new technologies in computation, communication, and sensing. Federal funding to enable universities to train the next generation of scientists and engineers is needed to enable this revolution. To realize practical quantum technologies, quantum expertise is needed through the full quantum stack—from materials, devices and hardware to software and algorithms. DOE NQI centers have been established to drive forward the research and training in select laboratories. These centers, however, do not address the need for shared quantum infrastructure for training and testbeds where Federal funding would serve a critical need.

At the University of Washington, the lack of critical capabilities, primarily originating from the large cost of implementing and maintaining them, hampers our impact. While we have targeted systems that work at room temperature, the leading quantum computing platforms work at ultra-low temperatures, just a fraction of a degree above absolute zero. Our researchers and students need access to this capability. We are able to provide our current capabilities by focusing on a single qubit platform which can function at room temperature at one particular energy. This particular platform at room temperature cannot scale to the many qubits required for meaningful quantum computation. We also need to seek to expand to enable the excitation and detection capabilities to discover new qubits which have the potential to scale even further.

The Boston Consulting Group estimates that quantum computing alone could create a value of $450 billion to $850 billion in the next 15 to 30 years if the technology scales as fast as predicted[1]. Quantum information science presents a tremendous economic opportunity and a substantial hurdle. One of the biggest issues impeding the growth of this industry is the shortage of an equipped quantum information science workforce. This shortage has a significant impact on the future growth of industry. In Washington state workforce development will impact the recruitment to existing Washington companies who have expanding footprints in quantum computing including Microsoft, Boeing, Amazon and Google as well as to new start-ups. It is increasingly difficult to fill skilled STEM job openings, which is further compounded for companies where advanced degrees in physics, chemistry, materials science, engineering and computer science are needed. As the investment and interest in quantum computing grows, competition for skilled workers is intensifying and

[1] Jean-François Bobier, Matt Langione, Edward Tao, and Antoine Gourevitch, "What Happens When 'If' Turns to When in Quantum Computing," Boston Consulting Group, 2021, *https://web-assets.bcg.com/89/00/d2d074424a6ca820b1238e24ccc0/bcg-what-happens-when-if-turns-to-when-in-quantum-computing-jul-2021-r.pdf.*

creating an unsustainable demand. This demand cannot be addressed without an accelerated and unrelenting investment in training and development.

According to a recent report from the Washington Roundtable, a nonprofit organization comprised of executives of major private sector employers in Washington state, in the next five years "Washington state's anticipated annual job growth rate of 2.3 percent will far outpace the national rate of 1.3 percent. Seventy percent of these jobs will require a post-high school credential. Washington employers want to hire local talent to fill these positions whenever possible and it's essential that our young people are ready."[2] At the University of Washington alone, student demand far exceeds capacity in the UW's engineering and natural sciences (including computer science and engineering, mathematical, physical and life sciences) programs. We are forced to turn away excellent students while our Nation demands a skilled workforce.

Failing to prepare our citizens for the innovation economy compromises our Nation's long-term competitiveness and economic stability and disadvantages our citizens and communities. Industry, government and universities must step up and invest in the quantum workforce. As we enter an increasingly specialized economy, America's leading research universities, including the University of Washington, are uniquely poised to provide leadership, research, and workforce education to meet this need, but we need Federal investment.

To be competitive we need to educate the workforce of the future and we know diverse teams lead to better results, so we are investing in programs to expand access to more Washington students, as well as asking for investment from the state. Students from low-income backgrounds, underserved public high schools, as well as first-generation college students, are particularly likely to suffer from financial, social, and emotional challenges, and struggle to adjust to college life and expectations. Our goal is to grow the infrastructure needed to support these students, many of whom arrive with little background or outside support necessary to navigate the rigorous coursework required for engineering and computer science. We measure our success in the students who graduate and move on to thriving careers in our Nation's industries. Central to our public mission, we strive to identify these students, recruit them, and enable them to succeed.

STEM creates a future of opportunity. It's a pipeline of local talent that will serve students, businesses, and communities across the nation, with benefits for decades. Through key relationships with industry, government, and academic partners, our Nation's universities can connect the best and brightest minds to advance quantum technology faster. The success of quantum information is closely aligned to ongoing fundamental science, which is why Federal investment is required. Federal leadership and investment are the foundation for these advances for all. As a representative of academia, we stand ready to partner with you. I ask that you continue to accelerate discovery through sustained and increased funding of the Federal agencies that enable us to remain a quantum information leader in a fierce global landscape. And I leave you with five areas where Federal investment would be particularly impactful: Increased funding for workforce development and education, support to develop accessible quantum testbeds and quantum cloud computing for all, increased funding for high-risk engineering and science research given the remaining technological barriers for quantum information science to become broadly usable, and more fundamental quantum information research and investment in technology policy.

Thank you for your time and consideration.

The CHAIR. Thank you, Dr. Albritton. And we look forward to asking you questions on that. And now we welcome Mr. Clark.

STATEMENT OF JACK CLARK, CO-FOUNDER, ANTHROPIC, CO-CHAIR, AI INDEX, MEMBER, NATIONAL AI ADVISORY COMMITTEE

Mr. CLARK. Chair Cantwell, Ranking Member Wicker, and members of the Committee, thank you for inviting me to testify today, and thank you for passing the CHIPS and Science Act. Your work is helping to set the United States up for continued leadership in

[2] Washington Roundtable, January 2022, *https://www.waroundtable.com/wp-content/uploads/2022/02/WRT_PostsecondaryEnrollmentCrisis_Report_1.2022.pdf.*

the development of transformative technologies such as artificial intelligence.

For this testimony, I will make recommendations to help the U.S. meet the challenge of international competition, ensure better collaboration between industry, Government, and academia, and grow a diverse workforce to meet the needs of our economy, all while ensuring the safe and responsible adoption of AI.

My recommendations are first, the U.S. should fully deliver the CHIPS and Science Act and make further investments in the measurement and monitoring of AI, both here and abroad. We need to know if we are in the lead, and if not, who is.

Second, the U.S. should build experimental infrastructure for the development and testing of AI systems by academic and Government's users, and so should be ambitious in how it supports the proposed National AI Research Resource. And third, we must prioritize the creation of testbeds for AI across the country, which can be used to train a new, diverse workforce in the art of assessing and deploying AI systems.

The U.S. today enjoys an enviable position in AI. We have a strong academic base, thriving commercial sector, and this hearing is an example, a Government that cares about how to support the industry.

AI systems have already made it out of the lab and are being used in the world. GitHub, a subsidiary of Microsoft, recently developed a tool called "Copilot," a spell checker for code. It helps programmers program better, and those that use Copilot are 50 percent faster than those that don't.

Researchers at Stanford have combined satellite imagery and machine learning to measure sustainable development outcomes in areas such as hunger relief, population density, and economic activity. And meanwhile, Google researchers have built translation technology for languages for which there is scarce data.

And using this, they have added 24 new languages to their translate service, letting all of us talk more to each other. And further afield, a new class of AI systems called Foundation Models are giving us the AI equivalent of Swiss Army knives, single software applications that can perform a multitude of tasks ranging from generating text and code, to helping people to create images and songs, to summarizing vast documents such as legislation.

But the U.S. can't rest on its laurels. AI is a competitive technology, and China already rivals for U.S. in AI R&D. In 2021, China published more AI research papers from the United States and filed more patents than any other country. The U.S. still holds the lead in the number of accepted papers and also in the number of citations its papers get but the gap is closing.

China has also proved capable of significant feats of AI engineering and research. Chinese scientists have won image recognition challenges, which were previously dominated by American companies. And Chinese companies like Huawei have been the first entities to publicly replicate frontier research published by American companies. So what do we do? I have two specific proposals.

As someone who spends their days in an AI lab, I can tell you that testing and evaluating AI systems is fundamental to realizing that commercial applications and identifying any safety issues.

Therefore, we must ensure that the National Institute of Standards and Technology is able to stand up AI testbeds across America so local communities can take AI systems out of the lab and vigorously test and deploy them. Second, we need better experimental infrastructure, here, big computers, because that is fundamental for research. For that reason, I wholeheartedly support the National AI Research Resource.

If we want America to benefit from AI, then we need to make it easier for our Nation's best scientists to build and experiment on it. And that is an opportunity the NAIRR gives us. In closing, the U.S. remains in a strong leadership position in the AI ecosystem, but China continues to close the gap.

For the U.S. to maintain its leadership, it should ensure adequate funding for AI research, computational infrastructure, and support for the measurement and assessment of AI systems. Ensuring strong domestic AI capabilities is paramount to protect our national security interests and ensure our continued economic competitiveness.

And Senators, I used an AI to write the last few sentences of this testimony. Thank you.

[The prepared statement of Mr. Clark follows:]

PREPARED STATEMENT OF JACK CLARK, CO-FOUNDER, ANTHROPIC, CO-CHAIR, AI INDEX, MEMBER, NATIONAL AI ADVISORY COMMITTEE

How testing and experimental infrastructure will let the United States take advantage of the industrialization of AI.

Chair Cantwell, Ranking Member Wicker, and members of the committee, thank you for the opportunity to speak with you today about the important topic of how the United States can maintain its leadership in emerging compute technologies. First, thank you for passing the CHIPs and Science Act. Through passing this, you have helped to set the United States of America up for continued leadership in the development and deployment of transformative technologies such as artificial intelligence.

For this testimony, I will make a few simple recommendations, which I hope will help us meet the challenge of international competition; increase opportunities for collaboration between the government, industry, and business sectors; and build a diverse and inclusive workforce to meet the growing demands of our evolving economy—all while ensuring the safe and responsible adoption of technology.

These recommendations are as follows:

- The United States should fully fund the CHIPS and Science Act, and make further investments in the measurement and monitoring of the artificial intelligence development ecosystem both domestically and abroad. Having accurate information about progress within the United States, among our allies, as well as progress occurring in other countries, is crucial for making good decisions about American technology strategy. We need to know if we're in the lead or if we're coming from behind, and where any gaps may be.
- The United States should seek to develop experimental infrastructure at scale for the development and testing of artificial intelligence systems by academic and government users. Concretely, the proposed National AI Research Resource can be best leveraged by pairing it with the creation of testbeds which can be used to train a new, diverse workforce in the important work of developing and assessing AI systems for economic applications and safety assurance.
- The United States should prioritize the development of resources for the assurance of AI—specifically, tools for the testing, evaluation, and benchmarking of artificial intelligence systems. The better we get at AI assurance, the more confidence we can have in AI systems, and the more we can create opportunities for collaboration across the private sector, government, and academia. Additionally, as more communities have the ability to test out different applications, they'll develop new products and services along the way.

Before I expand on these recommendations, I'd like to state why they're necessary, and why I'm so appreciative you are having a hearing about this now.

HOW WE GOT HERE

First, I want to provide an update on just how rapidly the field has been advancing. The past decade has been distinguished by what we can think of as the industrialization of artificial intelligence; AI has gone from an interesting topic of research and discussion among researchers, to something of real economic and strategic utility.

We can very roughly draw the "ignition point" for the industrialization of AI to 2012: this is when a team of researchers at the University of Toronto were able to win a highly-competitive image recognition competition known as ImageNet using a then-novel technique—taking a bunch of so-called neural networks, layering them on top of one another like a lasagne, and then training them on a significant amount of data [1]. The result was a system which set a new state-of-the-art on image recognition and which led to significant investments in AI by industrial actors here and abroad.

Since then, the field has notched up a few notable achievements. Systems like "AlphaFold" [2] have revolutionized the field of protein structure prediction, which is a key input to scientific development. Other AI systems have proven better able to stabilize the plasma in fusion reactors than any human or previous software system [3]. Meanwhile, AI has begun to make its way to the consumer so quickly that many do not realize they're already interacting with it throughout the day: voice recognition systems have improved substantially, we're all able to search through the photos on our phones now to find pictures of our dogs, cats, and family members.

These developments are fantastically exciting. Remember, ten years ago, none of these things were possible. Now they are. AI is now being applied in a vast range of fields, and we've barely scratched the service. Just to give you an idea of what is possible, here are a few examples of how AI is being applied today and the positive impact it is having on the world:

- *Enhancing developer productivity:* GitHub's Copilot product—an auto-completion tool used for computer programming tasks—has been shown to make software developers more than 50 percent faster in their work than developers that do not use the tool. The study also found higher levels of developer satisfaction, with 60–75 percent of users feeling less frustrated by daily programming tasks [4] (*GitHub*).
- *Estimating sustainable development outcomes:* Researchers at Stanford University have demonstrated how combining satellite imagery and machine learning can help measure sustainable development outcomes in areas such as hunger relief, population density, and economic activity [5] (*Stanford, Science*)
- *Measuring agricultural health:* Academic researchers have developed an image recognition system for detecting agricultural diseases in the cassava plant (a critical food source for millions of people across Africa), using just a mobile device [6] (*arXiv*).
- *Low-resource language translation:* Google researchers have found a way to develop translation technology for underrepresented languages using only text in the original language (traditional machine translation systems typically work with two sets of text: the original language text, and its translation to the target language). Using this new approach, Google was able to add 24 under-

[1] ImageNet Classification with Deep Convolutional Neural Networks, *https://papers.nips.cc/paper/2012/hash/c399862d3b9d6b76c8436e924a68c45b-Abstract.html,* 2012. One of the team members, Ilya Sutskever, went on to help found OpenAI, a major AI research company based in the United States.

[2] AlphaFold: a solution to a 50-year-old grand challenge in biology, *https://www.deepmind.com/blog/alphafold-a-solution-to-a-50-year-old-grand-challenge-in-biology,* 2020.

[3] Accelerating fusion science through learned plasma control, *https://www.deepmind.com/blog/accelerating-fusion-science-through-learned-plasma-control,* 2022.

[4] Quantifying GitHub Copilot's impact on developer productivity and happiness, *https://github.blog/2022–09–07-research-quantifying-github-copilots-impact-on-developer-productivity-and-happiness/,* 2022.

[5] Using satellite imagery to understand and promote sustainable development, *https://www.science.org/doi/10.1126/science.abe8628?cookieSet=1,* 2021.

[6] See: Using Transfer Learning for Image-Based Cassava Disease Detection, *https://arxiv.org/abs/1707.03717,* 2017.

resourced languages to its Translate service and develop a repeatable method to include other languages from around the globe[7] (*Google Research, arXiv*).

There are also exciting developments at the frontier; in the past few years, so-called "Foundation Models"[8] have emerged which show how AI is moving from an era of dedicated and specific tools to models that behave more like "Swiss Army knives"—a single model will be able to do a broad range of tasks, many of which are scientifically and economically useful.

These models are distinguished by the sizes of their datasets (extremely large datasets, ranging from hundreds of thousands of audio samples[9], to hundreds of millions of images[10], to billions of text documents[11]), the amount of computation required to train them (hundreds to thousands of specialized AI-training computer chips, running for months), to the complexity of the neural networks (which now number in the tens to hundreds of billions of parameters). Foundation Models have already proven to be useful: they can write and compose code, edit text, produce images, edit images, summarize documents, form the basis of question-and-answer systems, serve as potentially useful educational tools, and more.

However, the frontier is expensive: it costs millions to tens of millions of dollars to train these models and therefore they are being developed by only a small set of predominantly private sector actors. A challenge we must overcome is how to broaden the experimental infrastructure necessary to investigate these models, so that more Americans can participate in the development and analysis of them, and also learn the engineering and research skills they require.

These examples illustrate how broad the effects of the industrialization of AI are. But if we want to capture all the upside of this technology and mitigate its downsides, we also need to think about policies and investments that can support the burgeoning ecosystem, and assure the safety and reliability of the systems being developed within it.

WHY TESTBEDS, DATASETS, AND EVALUATION UNLOCK AI INNOVATION

While there are many reasons to be optimistic about the potential opportunities afforded by AI, there are also well-documented risks[12] and biases[13] inherent in many of today's applications. These risks and biases make it harder to deploy safe AI systems, and because these risks and biases are hard to identify, they can also lead to AI systems being deployed which have inequitable or harmful behaviors. However, we can mitigate these issues through pre-deployment and post-deployment testing, both of which the government can support—specifically, via the National Institute of Standards and Technology (NIST).

To maximize the potential of AI technologies, one important role the government can play is in developing a robust ecosystem for AI assurance. An assurance ecosystem allows multiple stakeholders to assess AI systems for performance and safety through a combination of shared testbeds, datasets, and evaluations. System assurance provides model developers with certainty in the reliability of their models, end users with trust that models will act as intended, and government stakeholders with confidence that systems are safe for the general public. We can imagine this assurance ecosystem as being analogous to how product safety standards give consumers confidence in things ranging from cars, to food, to drugs. It's definitely time to build out this ecosystem for AI.

Beyond improving the safety and reliability of AI systems, shared testbeds and evaluations enable a stronger R&D environment. Generally speaking, whenever a set of researchers create an artificial intelligence model, they then run that model through a large-scale battery of tests to assess model performance against previous iterations, as well as other results in the public domain. External benchmarks pro-

[7] See: Building Machine Translation Systems for the Next Thousand Languages, *https://arxiv.org/abs/2205.03983,* 2022.

[8] On the Opportunities and Risks of Foundation Models, *https://fsi.stanford.edu/publication/opportunities-and-risks-foundation-models,* 2021.

[9] Introducing Whisper, *https://openai.com/blog/whisper/,* 2022.

[10] Revisiting Unreasonable Effectiveness of Data in Deep Learning Era, *https://arxiv.org/abs/1707.02968,* 2017.

[11] An empirical analysis of compute-optimal large language model training, *https://www.deepmind.com/publications/an-empirical-analysis-of-compute-optimal-large-language-model-training,* 2022.

[12] The Malicious Use of Artificial Intelligence: Forecasting, Prevention, and Mitigation, *https://arxiv.org/abs/1802.07228,* 2018.

[13] What Do We Do About the Biases in AI?, *https://hbr.org/2019/10/what-do-we-do-about-the-biases-in-ai,* 2019.

vide an objective, baseline measure from which developers can compare and improve their systems.

At the same time, sometimes models are found to have capabilities that their developers did not anticipate, typically through end-users running novel or unexpected tests.[14] These tests can reveal both new capabilities as well as safety issues—for example, when GPT–3 was released, external users discovered that the system was able to perform some basic computer programming tasks as well as text-based tasks. Similarly, a few years ago, external researchers discovered that commercially deployed facial recognition systems displayed harmful biases, via a study named "Gender Shades".[15]

We already have examples of how these kinds of testing methodologies can be operationalized; following the publication of Gender Shades, NIST significantly updated its Facial Recognition Vendor Test (FRVT)[16] to include fine-grained, granular evaluations which were also sensitive to the demographic makeup of potential end-users of the system. This highlights how you can operationalize testing in a way that improves both the safety of the system (by reducing the likelihood of deploying unfair systems), and also giving confidence to end-users of the system that it is going to perform well.

Given the passage of the CHIPs Act and the funding it seeks to allocate to NIST, we should consider all the ways NIST can play an expanded role here. What might it look like to identify areas where industry and academia would benefit from more robust tests and to seek to create them? How might NIST construct fact-finding teams to identify some of the areas of greatest "evaluation need" and create tests in response? And can we take the in-development NIST AI Risk Management Framework (RMF)[17] and identify specific evaluation methodologies or tests that we might invest further in, so as to unlock even more economic innovation and increase the safety of such systems? (In my day job at the AI research company I am a co-founder of, Anthropic, I spend a lot of time trying to better evaluate our systems, and I can tell you that we generally try to incorporate all the tests that exist outside of Anthropic into our testing framework. We really can't get enough of them.).

These examples highlight the value of testing for both economic expansion, as well as improving the safety and reliability of AI systems.

WHERE OTHER NATIONS ARE

AI research and development is global. Most data sources tell us that, outside America, other key countries for AI R&D include the United Kingdom and, most pertinently for the field of international competition, China.

China and the U.S. can, in many ways, now be considered at roughly the same point in AI development. Both countries approach the development of the technology with different strengths and weaknesses that stem from their differing political structures, but both host burgeoning ecosystems of commercial AI companies, and both are supported by strong academic research infrastructure. The data bears this out:

- For example, while the U.S. leads in the number of global AI research paper conference citations each year (30 percent, over 15 percent from China in 2021), China continues to lead the world in the total number of AI *publications* (journal, conference, repository combined), with over 60 percent more than the United States in 2021 (*2022 AI Index)*
- As it relates to patents on AI technologies, China now files over half of the world's patents (51 percent in 2021). The U.S. still leads the percentage of *granted* AI patents globally, but that percentage has, on average, decreased over the past 7 years while the percentage of granted patents from China has steadily increased (*2022 AI Index*).

Beyond the basic metrics of academic publication, there are some qualitative examples I can share that illustrate how China has begun to advance its research and development of artificial intelligence.

ImageNet: Chinese teams became increasingly competitive at the aforementioned "ImageNet competition" in the 2010s. One Chinese team even won an image rec-

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[14] Predictability and Surprise in Large Generative Models, *https://arxiv.org/abs/2202.07785,* pg 4, 2022

[15] Gender Shades, *https://www.media.mit.edu/projects/gender-shades/overview/,* 2022

[16] Ongoing Face Recognition Vendor Test (FRVT), 36th edition of the report, *https://pages.nist.gov/frvt/reports/11/frvt_11_report.pdf,* 2022.

[17] NIST, AI RISK MANAGEMENT FRAMEWORK, *https://www.nist.gov/itl/ai-risk-management-framework,* 2022.

ognition challenge within that competition several years ago[18]. This is an extraordinarily competitive competition and being in the top-3 placed teams was typically considered impressive, and winning it is a proxy signal for competence. Put plainly: you win ImageNet by being extraordinarily good at training image recognition systems.

GPT–3: In 2020, an American AI research company called OpenAI (I worked there at the time) published a paper on a system called GPT–3. This system was a so-called large language model (LLM). LLMs are interesting to AI researchers because they are generic AI systems, capable of classifying and generating arbitrary text, and performing a broad range of tasks. LLMs are also distinguished by their cost: GPT–3 cost a lot of money to train, and involved using a large number of training accelerators (in this case, graphical processing units) to train a single neural network model; it could be considered a frontier capability due to this expense and complexity.

After publishing the paper about GPT–3 in May 2020[19], the first public replication of the system arrived in a paper in April 2021. The replication was a system called Pan-Gu and was developed by the Chinese telecommunications company Huawei[20]. Other replications followed (HyperCLOVA from Naver in Korea, and after that Jurassic-1-Jumbo from AI21 Labs in Israel). Notably, two more replications from Chinese labs followed in Huawei's footsteps, and this year a research group linked to Tsinghua University released GLM–130B, a GPT–3-style language model which is currently the best-performing language model[21] available as open source—and it's made in China.

Re-identification surveillance: China is far ahead of the United States in the development of surveillance technology. Specifically, we can look at re-identification; the task of identifying a person in security camera footage, then being able to see that person via a different security camera posed at a different angle and use a machine learning system to figure out it is the same person. This is a powerful and chilling capability which violates the norms and privacy protections we have in the United States. However, just because we wouldn't necessarily adopt a technology ourselves, it's worth noting when someone else is ahead on a given capability, no matter how distasteful. In re-identification, recent research shows that Chinese teams have continually pushed forward the state of the art, and are responsible for 58 percent of the top papers in the field[22]. Re-identification requires a combination of large datasets, the development of large-scale neural networks, and creative algorithm design. In other words, being good at re-identification means that you've built a decent AI competency, and it's worth noting that China is ahead here.

HOW THE UNITED STATES CAN SOLIDIFY AI LEADERSHIP

Besides continuing to invest aggressively in fundamental research, the United States has a couple of strategic policy investments it can make to bolster its leadership in artificial intelligence. I've already discussed the importance of making investments in testbeds, datasets, and evaluation to further unleash U.S. innovation here.

An additional lever we can use is the provisioning of experimental infrastructure for our academic community. Specifically, we should make it easier for America's best academic researchers to access computational power close to that found in industry, so that our universities can carry out ambitious experiments near the frontier of AI research; while it's likely industry will continue to define the frontier due to the increasingly large-scale resources being invested in model training, we should ensure academia is able to conduct experiments sufficiently close to it that they can help with the important work of safety validation and analysis of cutting-edge systems. This provides both accountability for the private sector, as well as letting our academic researchers design tools and techniques to improve systems deployed in the economy. We also need the necessary infrastructure to build testbeds for these systems so more people can spend time working out how to unlock their economic opportunities, and we can use these testbeds to include a much broader group in the testing and development of AI, which should help us grow the future AI workforce.

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[18] Large Scale Visual Recognition Challenge 2016 (ILSVRC2016), *https://www.image-net.org/challenges/LSVRC/2016/results.php,* 2016.

[19] Language Models are Few-Shot Learners, *https://arxiv.org/abs/2005.14165,* May 2020.

[20] PanGu-α: Large-scale Autoregressive Pretrained Chinese Language Models with Auto-parallel Computation, *https://arxiv.org/abs/2104.12369,* April 2021.

[21] For a detailed breakdown of performance, please refer to this GitHub page for the model: *https://github.com/THUDM/GLM–130B,* 2022.

[22] Measuring AI Development A Prototype Methodology to Inform Policy, *https://cset.georgetown.edu/wp-content/uploads/Measuring-AI-Development.pdf,* 2021.

For this reason, Anthropic firmly supports the goals of the National AI Research Resource ("NAIRR")[23]—a shared, public research infrastructure for academic researchers. We view its establishment as a necessary and excellent long-term investment in American AI research, as well as a critical resource for supporting the training and testing of AI systems. Increasing academic access to the infrastructure necessary to train increasingly resource-intensive models will build on the long and successful collaboration between academia and the U.S. government in creating transformative technologies and advancements across the U.S. economy. (We should also note that other parts of science already build large-scale experimental infrastructure, such as the particle physics community.)

From the 1960s until 2010, research shows that academia represented the majority of large-scale AI experiments. Between the early 2010s and today, the level of compute required for the largest scale experiments has increased by more than 300,000x—and the industry-academic balance has altered, with the vast majority of large-scale results now being carried out by industry rather than academia[24]. Few academics can afford the computing and engineering costs required to build and study large-scale AI models, such as Foundation Models which can cost millions of dollars to develop, and this is preventing some of our best researchers from working on problems found at the frontier. Even in Canada, where the country's advanced research computing (ARC) platform has allocated increasing quantities of compute to academics since the mid-2010s, the number of new applications for compute by Canadian researchers has grown at >10 percent a year—and demand still outstrips available supply.[25] Given academia's role in evaluating the safety and societal impacts of new technologies, we expect resources provided by the NAIRR will help restore a healthy balance between American universities and companies in cutting-edge AI research. Testbeds and other programs funded by the NAIRR will enable AI safety research and other research agendas in the public interest.

It's reasonable to ask why something like a NAIRR is necessary, given that AI is being developed and deployed by a large range of industry actors. After all, we might ask, isn't this a sign that the government should concentrate its efforts elsewhere? The answer is that by developing and funding a NAIRR, we're able to build infrastructure that will naturally serve as a proving ground for some of the ideas coming out of academia (and perhaps not yet mature enough to be adopted by industry), as well as creating infrastructure which is highly complementary with the testbeds NIST is tasked with building as part of the CHIPS and Science Act. Concretely, we might imagine the NAIRR serving as a resource for universities to develop large-scale AI systems, then we can also use the computational power of the NAIRR to facilitate a broad spread of universities to run testbeds to see how well we can turn these systems to often neglected problems; improving the way we manage our farms, building sensing systems to help us respond to natural disasters, figuring out ways to make our transport and logistical systems more efficient, and so on. This would also be directly enabling for another key aspect of CHIPS and Science—the NSF's new Technology, Innovation, and Partnerships directorate.

We suspect many of the best ideas for how to harness AI are going to come from universities across America working to solve problems relevant to their own communities, giving more institutions a role in assuring that AI systems are safe, reliable, and well-calibrated to the problems they are designed to solve. Local context is vital to ensure tools are well-designed. AI logistics systems will best serve the Port of Gulfport or the Port of Seattle if local port employees and nearby universities help inform those systems. These tools will underperform if they are only pressure-tested in distant labs, rather than by researchers close to local contexts.

Another example is in healthcare: AI shows significant promise to enhance healthcare, such as applications that aid in diagnostics or recommending treatments. However, due to differences between hospitals, such as imaging equipment, procedures, and local population demographics, AI algorithms that may work well at one hospital can perform very poorly at another. One solution to this problem involves more collaborations between universities and their local hospitals to develop, test, and fine tune models to serve regional needs, which can be facilitated by testbeds in combination with the NAIRR. The NAIRR can also help us work on some of the challenges of the governance of increasingly capable AI systems. By

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[23] THE NATIONAL ARTIFICIAL INTELLIGENCE RESEARCH RESOURCE TASK FORCE (NAIRRTF), *https://www.ai.gov/nairrtf/*.

[24] Addendum: Compute used in older headline results, *https://openai.com/blog/ai-and-compute/*, 2019.

[25] 2022 Resource Allocations Competition Results, Digital Resource Alliance of Canada, *https://alliancecan.ca/en/services/advanced-research-computing/accessing-resources/resource-allocation-competitions/2022-resource-allocations-competition-results*

making available experimental infrastructure for large-scale experimentation, the NAIRR creates an opportunity to think about how we govern that experimental infrastructure. Which experiments should get authorized for using a large amount of NAIRR resources?[26] How do we test and evaluate the systems that result from these experiments?[27] Which people should participate in the analysis and curation of the datasets which are used to develop models on the NAIRR? Once a system is developed on the NAIRR, how might organizations such as NIST help assure the resulting system for safety? These are all extraordinarily valuable things to work on in public, rather than in private as is done today by most industry actors. Beyond enhancing economic competitiveness and safety, the NAIRR may also help us identify smart, lightweight regulations that will be fit for the increasingly powerful AI models that will distinguish this new period of industrialization.

CONCLUSION

In conclusion, I'd like to thank this committee for its important role in the CHIPS and Science Act, enthusiastically support full appropriation for its programs, and recommend that the additional investments that the bill proposes be made in testbeds, datasets, and evaluation as a means of unlocking economic innovation and unlocking revolutionary scientific research.

Additionally, I want to offer strong support for the establishment of the National AI Research Resource, a national infrastructure built to facilitate academic AI research that can also help make sure the United States stays ahead in one of the most important technology developments we are seeing today. The NAIRR will ensure that American scientists keep our Nation at the forefront of understanding frontier compute technology, creating important research and workforce opportunities and new avenues for economic growth.

Thank you for the chance to speak. I'll be happy to answer any questions you have about my testimony.[28]

The CHAIR. Do you want to explain that?

Mr. CLARK. Yes. I fed the first two pages of a testimony to an AI language model that Anthropic developed and then it wrote the last paragraph. And then I added for, and Senators, part myself to indicate to you it was written by an AI rather than me.

The CHAIR. And it compiled a summation from the data points that had previously been mentioned? What do you think the——

Mr. CLARK. It read the text and tried to predict what a good finishing conclusion would be. I also said, please write the conclusion. I tend to be polite to it as well.

The CHAIR. Thank you. Mr. Breckenridge.

Mr. CLARK. Top that.

[Laughter.]

Mr. BRECKENRIDGE. Right.

[Laughter.]

STATEMENT OF WILLIAM B. (TREY) BRECKENRIDGE III, DIRECTOR, HIGH PERFORMANCE COMPUTING COLLABORATORY, MISSISSIPPI STATE UNIVERSITY

Mr. BRECKENRIDGE. Chairman Cantwell, Ranking Member Wicker, and members of the Committee, thank you for the opportunity to speak today about a topic that is both timely and critical to our Nation's global competitiveness and security. As many experts have

[26] Centre for the Governance of AI Submission to the Request for Information (RFI) on Implementing Initial Findings and Recommendations of the NAIRR Task Force, *https://www.governance.ai/research-paper/submission-nairr-task-force,* 2022.

[27] Anthropic response to Request for Information (RFI) on Implementing the Initial Findings and Recommendations of the National Artificial Intelligence Research Resource Task Force *https://www.ai.gov/rfi/2022/87-FR-31914/Anthropic-NAIRR-RFI-Response-2022.pdf*

[28] I used an Anthropic 'Foundation Model' to write the 'CONCLUSION' section of this testimony. I added some specific language and tweaked a couple of words, but other than that, the text is what the AI generated. I hope this illustrates how these technologies are already changing how we work today.

highlighted, U.S. research investment has fallen woefully behind our adversaries in areas that are critical to our national security.

The topic of this hearing are certainly at the top of the list if we are to sustain and protect our Nation as a world leader. My perspective comes as Director of the High Performance Computing Laboratory at Mississippi State University, where I have served for the past 30 years.

Our high performance computing capacity provides support for research in artificial intelligence, autonomous vehicles, cybersecurity, data science, weather modeling, and other areas of applied research vital to the prosperity of the United States and the world.

I am extremely proud of the national presence MSU holds in high performance computing and the advancement of science enabled by our HPC systems. Mississippi State University has had a presence on the world's top 500 fastest computers list since 1996. At its debut in 2019, our Orion supercomputer, a 5.5 petaflops system, operated in partnership with NOAA, ranked 60th in the world and 5th in U.S. academia.

Much of the growth and success that Mississippi State University has enjoyed in high performance computing can be directly attributed to the partnerships we have built with agencies such as NOAA, NSF, Department of Agriculture's Agricultural Research Service, and the DOD.

With respect to international HPC capability, according to the top 500 supercomputing sites list, in 2012 the U.S. was home to more than 50 percent of the world's 500 fastest computers, while China had less than 14 percent.

Today, the U.S. is home to only 23 percent of the world's 500 fastest computers, while China has increased their share to over 45 percent. Furthermore, China has significantly increased HPC funding to match or exceed the U.S. HPC capacity at the very high end.

The fastest system on the latest top 500 list is located in the U.S., however many experts are confident that China has secretly built two systems that rival the performance of the fastest U.S. system. Simply put, our adversaries are outspending us in high performance computing. As you well know, artificial intelligence and blockchain rely heavily on HPC and the next major advance in computing will most likely occur with quantum technology.

Quantum holds the potential to solve complex problems that are unable to be solved with classical computing systems, but it also presents many challenges that must be overcome with significant investments. As an example, in the field of cybersecurity, quantum technology will place much of today's public key encryption at risk.

The development of robust quantum based encryption techniques and the use of quantum machine learning to detect and defeat novel cyber-attacks are crucial. These challenges are not just in the development and maturation of hardware, but perhaps more importantly, the creation and training of a knowledgeable workforce that is able to develop new software tools and enable access to the broader scientific community without the need for understanding quantum physics.

The recent passage of the CHIPS and Science Act has been heralded as a necessary action for the United States to match investment in these critical technology areas that are being heavily funded by those in the international community looking to displace the U.S. as a leader in technology development and deployment.

We have certainly experienced it recently with the global chip shortage based on China dependence and we have strong evidence that their investment in quantum and AI is clearly outpacing our investment. The CHIPS and Science Act is an excellent first step to combat this issue.

I would also like to applaud the bill sections related to the EPSCoR funding and impacts it will have to vastly expand the talent base in critical fields necessary to remain a global leader. We have proven that EPSCoR institutions like MSU can be a national leader in technology fields such as high performance computing, contributing to the advancement of necessary technology, while playing a significant role in cultivating the workforce of tomorrow's innovative leaders.

I offer the following recommendation for the Committee to consider. To remain globally competitive and protect our future, investments such as the CHIPS and Science sector are critical to maintain our national security to mitigate being outpaced by adversary nations whose primary goal is to relegate the U.S. to a second tier technology nation.

We must utilize the expertise that exists throughout the U.S. and grow the technology workforce, not in just existing U.S. technology centers, but throughout the country. Finally, Federal, State, and university partnerships will be critical to addressing these issues and being unified in developing solutions.

Thank you for the opportunity to testify before you today. Bipartisan support of technology and innovation is critical to our competitiveness, and Mississippi State University stands prepared to be full participants in support of your efforts.

[The prepared statement of Mr. Breckenridge follows:]

PREPARED STATEMENT OF WILLIAM B. (TREY) BRECKENRIDGE III, DIRECTOR, HIGH PERFORMANCE COMPUTING COLLABORATORY, MISSISSIPPI STATE UNIVERSITY

Chairman Cantwell, Ranking Member Wicker and members of the committee, thank you for the opportunity to speak today about a topic that is both timely and critical to our Nation's global competitiveness and security. As many experts have highlighted, U.S. research investment has fallen woefully behind our adversaries in areas that are critical to our national security. The topics of this hearing are certainly at the top of that list if we are to sustain and protect our Nation as a world leader.

My perspective comes as the Director of the High Performance Computing Collaboratory at Mississippi State University where I have served for the past 30 years. Our high performance computing capacity provides support for research in artificial intelligence, autonomous vehicles, cybersecurity, data science, weather modeling and other areas of applied research vital to the prosperity of the United States and the world. I am extremely proud of the national presence MSU holds in high performance computing and the advancement of science enabled by our HPC systems. Mississippi State University has had a presence on the world's TOP500 fastest computers list since 1996. At its debut in 2019 our *Orion* supercomputer, a 5.5 petaFLOPS system operated in partnership with NOAA, ranked 60th in the world and 5th in U.S. academia. Much of the growth and success Mississippi State University has enjoyed in high performance computing can be directly attributed to the partnerships we have built with agencies such as NOAA, NSF, the Department of Agriculture's Agriculture Research Service, and the DOD.

With respect to international HPC capability, according to the TOP500 Supercomputing Sites list, in 2012 the U.S. was home to more than 50 percent of the world's 500 fastest supercomputers while China had less than 14 percent. Today the U.S. is home to only 23 percent of the world's 500 fastest computers while China has increased their share to over 45 percent. Furthermore, China has significantly increased HPC funding to match or exceed the U.S. HPC capacity at very high end. The fastest system on the latest TOP500 list is located in the US, however many experts are confident that China has secretly built two systems that rival the performance of the fastest U.S. system. Simply put, our adversaries are outspending us in high performance computing.

As you well know, Artificial Intelligence and Blockchain rely heavily on HPC, and the next major advance in computing will most likely occur with Quantum technology. Quantum holds the potential to solve complex problems that are unable to be solved with classical computing systems, but it also presents many challenges that must be overcome with significant investments. As an example, in the field of cybersecurity, quantum technology will place much of today's public-key encryption at risk. The development of robust quantum-based encryption techniques and the use of quantum machine learning to detect and defeat novel cyber-attacks are crucial. These challenges are not just in the development and maturation of hardware, but perhaps more importantly, the creation and training of a knowledgeable workforce that is able to develop new software tools and enable access to the broader scientific community without a need for understanding quantum physics.

The recent passage of the CHIPS and Science Act has been heralded as a necessary action for the United States to match investment in these critical technology areas that are being heavily funded by those in the international community looking to displace the U.S. as a leader in technology development and deployment. We have certainly experienced that recently with the global chip shortage based on China dependence, and we have strong evidence that their investment in quantum and AI is clearly outpacing our investment. The CHIPS and Science Act is an excellent first step to combat this issue. I would also like to applaud the bill sections related to EPSCoR funding and the impacts it will have to vastly expand the talent base in the critical fields necessary to remain a global leader. We have proven that EPSCoR institutions like MSU can be a national leader in technology fields such as high performance computing, contributing to the advancement of necessary technology while playing a significant role in cultivating the workforce for tomorrow's innovative leaders.

I offer the following recommendations for the committee to consider. To remain globally competitive and protect our future, investments such as the CHIPS and Science Act are critical to maintain our national security to mitigate being outpaced by adversary nations whose primary goal is to relegate the U.S. to a second-tier technology nation. We must utilize all the expertise that exists throughout the U.S. and grow the technology workforce, not just in existing U.S. technology centers but throughout the country. Finally, federal, state and university partnerships will be critical to addressing these issues and be unified in developing solutions.

Chairman Cantwell, Ranking Member Wicker, members of the committee, I thank you for the opportunity to testify before you today. Bipartisan support of technology and innovation is critical to our competitiveness and Mississippi State University stands prepared to be full participants in support of your efforts.

The CHAIR. Thank you for that testimony. We will now go remotely to Mr. Steve Lupien, am I saying that correctly? Hold on a second, Mr. Lupien. Hold on 1 second. We don't have your audio.

Mr. LUPIEN. Can you hear me now?

The CHAIR. Yes. Thank you so much. Thank you.

STATEMENT OF STEVEN C. LUPIEN, DIRECTOR, UNIVERSITY OF WYOMING CENTER FOR BLOCKCHAIN AND DIGITAL INNOVATION

Mr. LUPIEN. Chairman Cantwell, Ranking Member Wicker, and members of the Committee, thank you for the opportunity to testify today on the topic of distributed ledger systems and how the U.S. can maintain our leadership in this nascent technology. And also thank you for passing the CHIPS and Science Act.

My name is Steve Lupien. I am a Lecturer in Digital Assets at the University of Wyoming's College of Business and Director of the University's Interdisciplinary Center for Blockchain and Digital

Innovation. I specialize in the many ways that digital assets are disrupting business and financial systems.

In my educational capacity, I am often asked to explain what blockchains are. And simply put, they are just a new type of database that allows multiple people to see the same information at the same time and provide trust that that information is valid. Blockchains make data unique, and that is their true power.

Data on a blockchain is immutable, encrypted, yet private, and allows trust to be written into code and not left to third party intermediaries. I have been fortunate to work directly in many of the forward looking regulation that Wyoming has enacted over the last several years. Currently, Wyoming has passed 30 bills.

The first is a token taxonomy bill defining digital assets under the law. I believe both the House and Senate are looking at that presently. We are the first to map digital assets to existing UCC law, which I think is important to give businesses certainty in this space. We created a FinTech sandbox to allow businesses to innovate under regulatory supervision.

And probably the most important thing we did was passed groundbreaking legislation called the Special Purpose Depository Institution Bill that creates regulated banks for both U.S. dollar deposits and digital assets.

Unlike many in this space, I believe that digital assets should be allowed to flourish under appropriate regulatory guardrails while allowing latitude for experimentation, development, and growth. I don't see digital assets as a threat to our existing financial and business systems, but instead as an enhancement that will allow the U.S. to maintain our lead in finance and business long into the future.

However, the industry is receiving mixed signals from regulators to date, and we need to align on a comprehensive regulatory framework that removes any uncertainty and allows businesses the legal clarity they need to experiment and grow this technology. Digital assets can encompass much more than just cryptocurrency.

They are being used for highly efficient supply chain tracking systems, frictionless and speedy payment systems, smart contracts that allow businesses to automate countless contractual agreements, and token—and tokenization of physical assets through nonfungible tokens, NFTs, that not only allow the tokenization of intellectual property like artwork, but also innovations such as ESG tokens for energy source identification, carbon capture, carbon sequestration, and even environmental habitat protection just to name a few.

The U.S. Government has just begun to fund research projects in this space, and I encourage you to explore opportunities to partner with universities more in discovering how digital assets can bring about financial and business leadership as well as public good. Please consider the role of rural universities in this space.

We are often out in front. For example, the University of Wyoming was the first Division 1 university to offer a degree program in blockchain, a minor in blockchain, the first to build and operate an educational Bitcoin mining lab, and the first to operate a proof of stake staking pool. I am also a very strong advocate of fostering digital literacy.

My center recently received funding through the Wyoming Innovation Partnership with seed funding from the American Rescue Plan to develop educational programs for Wyoming's high schools and community colleges. The goal of these programs are to introduce students to the many options available to them in STEM in general and blockchain in particular.

We have a secondary goal of encouraging more girls and women and these—to these opportunities as they are presently underrepresented in the workforce. And I encourage you to look at how programs such as these can be made nationwide.

Just this month, the U.S. Department of Commerce published a report titled, Responsible Advancement of U.S. Competitive and Digital Assets.

In this report, they highlighted several categories that I support, and I ask you to do so also, including ensuring effective regulatory approaches for addressing regulatory gaps, fostering meaningful public-private engagement to ensure that digital asset stakeholders across multiple business sectors and Federal departments and agencies can meet regularly to discuss important issues, and sustain leadership in technological research and development that will be advanced for activities such as increased investment in the Government, academic, and industry led research.

I thank you all for your time and consideration and welcome any questions you have.

[The prepared statement of Mr. Lupien follows:]

PREPARED STATEMENT OF STEVEN C. LUPIEN, DIRECTOR, UNIVERSITY OF WYOMING CENTER FOR BLOCKCHAIN AND DIGITAL INNOVATION

APPLICATIONS OF DIGITAL LEDGER TECHNOLOGY AND HOW THE U.S. CAN BETTER COMPETE

Chairman Cantwell, Ranking Member Wicker and members of the committee, thank you for the opportunity to testify today on the topic of Distributed Ledger Systems and how the U.S. can gain and then maintain our leadership in this nascent technology. My name is Steven Lupien, and I am a Lecturer in Digital Assets at the University of Wyoming's College of Business and Director of the University's interdisciplinary Center for Blockchain and Digital Innovation (CBDI).

I am an expert in the many ways that digital assets are disrupting business and financial systems and the co-author of the textbook *Blockchain Fundamentals for Web 3.0* published in August 2022 by the University of Arkansas Press: Link

In my educational capacity, I am often asked to explain what blockchain are. Simply put, they are a new type of database that allows multiple people to see the same information at the same time and provide trust that the information is valid. Blockchains make data unique, and that is their true power. Data on a blockchain is immutable, encrypted yet private, and allows trust to be written in code, and not left to third-party intermediaries.

I have been directly involved in much of the forward-looking regulation that Wyoming has enacted, currently 30 Bills since 2017, that include:

- The first Token Taxonomy bill defining digital assets under the law,
- Mapping digital assets to existing UCC Law,
- Creating a Fintech Sandbox to allow businesses to innovate under regulatory supervision, and
- The ground-breaking Special Purpose Depository Institutions (SPDI) bill creating regulated banks for both U.S. dollar deposits and digital assets.

Unlike many in this space, I believe that digital assets should be allowed to flourish under *appropriate* regulatory guardrails while allowing the latitude for experimentation, development, and growth. I don't see digital assets as a threat to our existing financial and business systems, but instead as enhancements that will allow the U.S. to maintain our lead in finance and business, and as the world's reserve currency long into the future.

However, the industry is receiving mixed signals from regulators to date, and we need to align on a comprehensive regulatory framework that removes any uncertainty and allows businesses the legal clarity that they need to experiment and grow this technology.

Digital assets encompass much more than just "cryptocurrency," they are being used for highly efficient supply train tracking, frictionless and speedy payment systems, smart contracts that allow businesses to automate countless contractual agreements, and the tokenization of physical assets through non-fungible tokens (NFT's)—that not only allow the tokenization of intellectual property, like artwork, but also innovations such as ESG tokens for Energy Source Identification, Carbon Capture, Carbon Sequestration, and even environmental habitat protection, to name just a few.

The U.S. government has been slow to fund research projects in this space, and I encourage you to explore opportunities to partner with universities in discovering how digital assets can bring about financial and business leadership as well as public good—please consider the role of rural universities in this space, we are often out in front. For example, the University of Wyoming was the first D–1 university to offer a degree program in blockchain (Minor in Blockchain), the first to build and operate an education Bitcoin mining lab, and the first to operate a proof-of stake staking pool.

I am also a very strong advocate of fostering digital literacy. My center recently received funding through the Wyoming Innovation Partnership (WIP) with seed funding from the American Rescue Plan (ARP) to develop education programs for Wyoming's high schools and community colleges. The goal of these program is to introduce students to the many options available to them in STEM in general and blockchain in particular. We have a secondary goal of introducing girls and women to these opportunities as they are presently underrepresented in the workforce. I encourage you to look at how programs such as these can be made available nationwide.

The U.S. Department of Commerce published a report this month titled, RESPONSIBLE ADVANCEMENT OF U.S. COMPETITIVENESS IN DIGITAL ASSETS. In this report, they highlighted several categories that I support, and ask that you do also, including:

- Ensuring effective regulatory approaches and addressing regulatory gaps. This will support the development of a healthy market that nurtures competition and responsible innovation while safeguarding consumer and investor interests, market integrity, financial stability, and national security.
- Fostering meaningful public-private engagement to ensure that digital asset stakeholders across multiple business sectors and Federal departments and agencies can regularly meet to discuss issues of import to the digital asset sector and identify areas where coordination may need to occur. Please include rural universities here, as well.
- Sustained leadership in technological research and development (R&D) that will be advanced through activities such as increased investment in government, academic, and industry-led research, workforce development, and digital literacy.

I thank you all for your time and consideration and welcome any questions you have.

The CHAIR. Thank you, Mr. Lupien. We will now turn to Dr. Bob Sutor. Welcome. Thank you for your presence here today.

STATEMENT OF DR. BOB SUTOR, VICE PRESIDENT, CORPORATE DEVELOPMENT, COLDQUANTA

Dr. SUTOR. Thank you. Chairperson Cantwell, Ranking Member Wicker, and members of the Committee, thank you for the opportunity to speak to you today on behalf of the ColdQuanta Corporation.

I will start with the bottom line, quantum technology and computing will fundamentally and profoundly change how we live and do business. It can significantly transform our economy, national security, and the daily lives of Americans. Congress and the White House have taken bold and important steps to secure our quantum future through legislation like the CHIPS and Science Act and the earlier National Quantum Initiative.

We must now accelerate the development of this technology in parallel with building a robust domestic supply chain and workforce. Quantum computers are only in the early stages of development. The number of qubits or quantum bits that known quantum computers have today range from single digits to slightly more than 100.

Practical quantum computers will need hundreds of thousands to millions of qubits for the applications we need. With quantum computing, we could develop new materials and substances, including medicines, antibiotics and antiviral drugs, and design new, more efficient lithium batteries for transportation.

We could find new alloys for aerospace, automotive, and military use. I am confident we will get there. Now, if there is one thing we have learned repeatedly in the nearly 80 years of the modern computing era, computers get smaller and more powerful. We put computers and more of them in places we don't expect. Edge computing works with data close to where it is created or used.

We could put quantum computers in cell phone towers and factories. We will want this processing capability on planes, ships, submarines, and even satellites. To achieve this, the United States must invest in scaling up the power of quantum systems while scaling down their size and cost for use at the edge.

A data center only strategy will leave us vulnerable to not having the compute resources we need where we need them. Quantum has many other applications beyond computing, positioning, navigation, and timing, or PNT, concerns accurately locating ourselves and moving to where we need to be.

News Report states that foreign powers spoof and deny GPS services to confuse and disadvantage their enemies at war. Quantum inertial sensors, including accelerometers and gyroscopes and quantum atomic clocks should be able to replace GPS, prevent spoofing, or act as a backup in case of local and catastrophic service failure.

For commercial, defense, and intelligence—from commercial, defense, and intelligence perspectives, quantum sensors could provide these required, stable, and accurate measurements for our use on land, at sea, and in space.

Quantum gravity sensors could assist in finding new energy in mining resources and detect underground facilities not apparent from visual examination. In what I think is a massive understatement, quantum is not easy. These systems require significant investment, scientific progress, engineering innovation, education, and skills development to bring into being. We should not wait.

We must secure our domestic quantum supply chain for necessary enabling components such as lasers and photonic integrated circuits. Only with a reliable supply chain can the United States guarantee it can build the computers and sensors our nations need. All of this will require a significant quantum workforce, and it will not be limited to those with doctorates.

We will need trained manufacturing and IT workers, and software and hardware engineers. There will be many new jobs and new types of jobs. We must strengthen our education in computer science, physics, mathematics, and engineering if we expect to have a national workforce with the necessary skills to build and use quantum tech.

Quantum companies need support. There is currently a shortage of Federal assistance to help small quantum companies transition their promising cutting edge technology now under development to prototyping, and then to production, scale, and capability. We must strengthen and accelerate the academia, Government, commercial collaboration to get practical and pervasive quantum technologies in the next several years instead of the next several decades.

We require better procedural and program mechanisms to navigate the so-called valley of death stage of development, where we have scattered investment without integration into deployed systems of record. We need to do more to track, manage, and coordinate the many individual Federal quantum R&D projects across the Government.

We must ensure gaps are understood and covered, most promising technology is fast tracked and well-supported, and overlaps and duplications are removed. Thank you for the opportunity to speak with you.

[The prepared statement of Dr. Sutor follows:]

PREPARED STATEMENT OF DR. BOB SUTOR, VICE PRESIDENT, CORPORATE DEVELOPMENT, COLDQUANTA, INC.

Chairperson Cantwell, Ranking Member Wicker, and Members of the Committee, thank you for the opportunity to speak with you today on behalf of the ColdQuanta corporation regarding our Nation's leadership position in quantum computing and other emerging quantum technologies.

The bottom line

I will start with the bottom line: quantum technology and computing will fundamentally and profoundly change how we live and do business. It has the potential to transform completely our economy, national security, and the daily lives of all Americans, including discovering new medicines, engineering better batteries, and creating many new jobs.

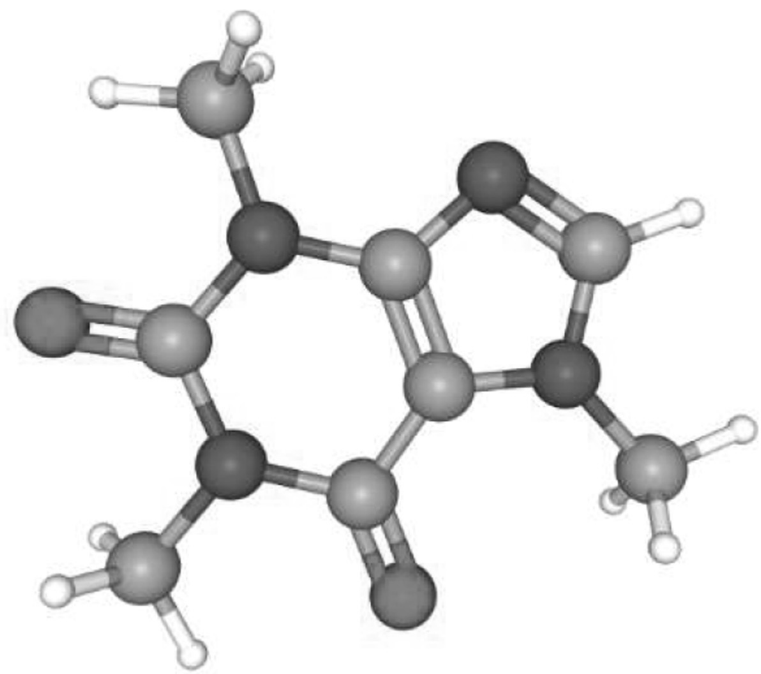
There is a global quantum race happening. We are not the only country that recognizes the potential of quantum technology. If we do not make new strategic investments and organize more effectively at the Federal level to accelerate the domestic development of quantum, we could lose.

Science, not fiction

Based on my experience in the quantum industry, I want to share with you how revolutionary quantum information science and technology are.

The word "quantum" may conjure up thoughts of science fiction, with television shows such as *Quantum Leap* and movies like *Ant-Man and the Wasp* bringing the "quantum realm" into popular culture. Luckily for us, technologies like quantum computing, quantum inertial sensors, quantum radio-frequency receivers, and atomic clocks are anything but fiction.

To give you a realistic example of what quantum computing is capable of, let's consider the field of chemistry. In this area, we expect to see many impactful quantum computing applications. We base quantum computing on the principles of quantum mechanics, which explains the behavior of atoms, electrons, and photons (or particles of light). Modeling chemical behavior at the atomic level is notoriously difficult and slow, and it is often necessary to sacrifice the accuracy of the solution to get an answer in a reasonable amount of time, even with massive computer resources.



The caffeine molecule

A molecule that most of us are intimately familiar with is caffeine. Though caffeine has a notable effect on us, it is a small and relatively simple molecule. Surely we should be able to model on a computer how caffeine operates on our brain to keep us awake and alert. Using a classical computer, we represent information with bits, or zeros and ones. However, to perfectly represent a single caffeine molecule in a classical computer, we estimate we would need

10^{48} = 1000000000000000000000000000000000000000000000000

bits of information. For comparison, scientists estimate that if you counted up the entirety of the atoms in the earth, every rock and human and molecule of air or drop of water, that number is between 10^{49} and 10^{50}.

So to model just one caffeine molecule with a classical computer, we would need an amount of storage comparable to 1 to 10 percent of the size of the earth. We will never see this with the classical computer technology we use today.

The promise of quantum computing

Quantum computing can do better. Through the quantum mechanical properties of “entanglement” and “superposition,” quantum computing promises to solve problems that classical computers could never hope to do in our lifetimes (or our great, great, great grandchildren’s lifetimes). In quantum computing, we use “qubits” or “quantum bits” instead of bits. We expect to be able to represent caffeine using only 160,000 qubits. With quantum computing, we could develop new medicines, antibiotics, and antiviral drugs and design new and much more efficient lithium batteries for transportation. If we could discover new catalysts for creating fertilizers, we could have far more sustainable processes supporting agriculture that use much less energy. And we could find new alloys and materials for aerospace, automotive, and military use.

However, it is essential to note that quantum computers are in the early stages of development. How large are the qubit counts of quantum computers we know of today using public information? These range from single digits to slightly more than

100. In 2021, a team from the University of Science and Technology of China announced that they had built a 62-qubit computer.[1]

Quantum computing intersects with cybersecurity because it may be possible someday to break several kinds of encryption methods we use today. A recent estimate puts the necessary qubit count for a successful attack at approximately 20 million.[2] In July, the United States National Institute of Standards and Technology announced four new "quantum-resistant" cryptographic protocols that should withstand attack via future quantum computing systems.[3]

Taking quantum to the Edge

I believe many people make the mistake of only thinking of "quantum supercomputers" living in data centers, taking up a lot of room, and having significant energy requirements. If there is one thing we have learned over and over in the nearly 80 years of the modern computing era, computers get smaller and more powerful. We put more of them in places we did not expect. Your smartphone might have been a supercomputer 30 or 40 years ago. We must consider computing and data at the Edge.

Astronaut Christina Koch with NASA's Cold Atom Lab and ColdQuanta technology "at the Edge" aboard the ISS.

Edge computing works with data close to where it is created or used. We might put a quantum computer in a cell phone tower or factory. We will want significant processing capabilities on planes, ships, submarines, and perhaps even satellites. We cannot always bring information back into a data center.

In military situations, we may not be connected to centralized computing resources. We expect to use quantum computers for AI and optimization problems like logistics. One of the areas of great interest at the Edge is federated or distributed machine learning for AI applications.

The United States must invest in scaling up the power of quantum systems while scaling down their size and cost for use at the Edge. A "data center-only" strategy

[1] *https://thequantuminsider.com/2021/05/10/chinese-research-team-designs-builds-62-qubit-superconducting-quantum-computer/*

[2] *https://quantum-journal.org/papers/q-2021-04-15-433/*

[3] *https://www.nist.gov/news-events/news/2022/07/nist-announces-first-four-quantum-resistant-cryptographic-algorithms*

may leave us vulnerable to not having the compute resources we need where we need them.

The start of the marathon

These systems require significant investment, scientific progress, engineering innovation, education, and skills development to bring into being. We should not wait. If we hesitate or under-invest, other nations could take the lead in creating and using these technologies for commercial and military applications. Through legislation like the CHIPS Act and the earlier National Quantum Initiative, Congress and the White House have already taken important steps to begin to secure our quantum future. More is needed. We need to accelerate the development of this technology and do this in parallel with building a robust domestic supply chain and workforce.

The race is on, but we have a long way to go to perfect usable quantum computers. We must rapidly scale these systems to make them usable.

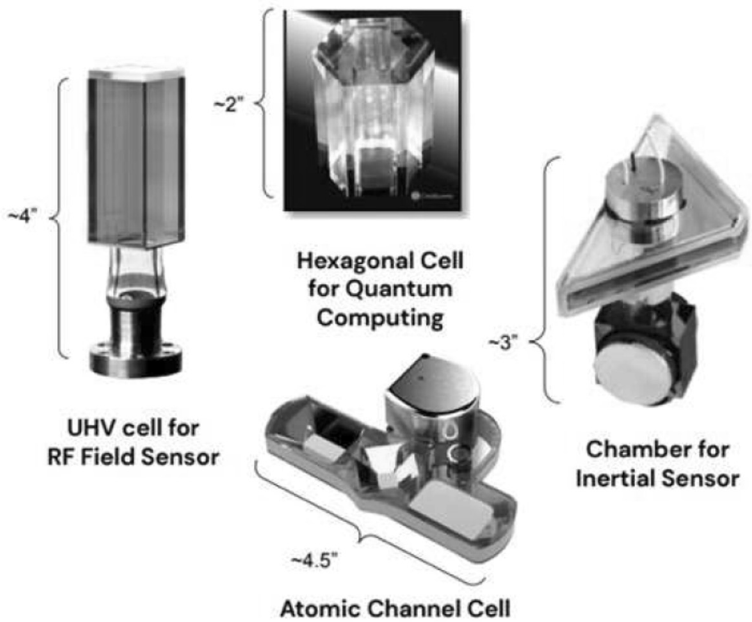
Other types of quantum technology—such as quantum inertial sensors, quantum radio-frequency receivers, and atomic clocks—are much closer to becoming fieldable devices. These have the potential to protect against GPS denial and improve intelligence gathering with high sensitivity receivers in the next few years, not decades. Investments in these technologies will feed back into and accelerate our quantum computing development. My company, ColdQuanta, uses "cold atom" technology we have already deployed on the International Space Station with the Jet Propulsion Laboratory to build our qubits.[4] We expect systems based on cold atoms to scale up to the needed range.

Quantum sensors for the near term

"Quantum" has many other applications. Positioning, navigation, and timing, or "PNT," concerns accurately locating ourselves and moving to where we need to be. Doesn't GPS, the Global Positioning System, already give us this? News reports have stated that foreign powers have spoofed or denied GPS services to confuse and disadvantage their enemies at war. Quantum inertial sensors, including accelerometers and gyroscopes, and quantum atomic clocks, should be able to replace GPS, prevent spoofing, or act as a backup in case of local and catastrophic service failure.

Commercially, these can benefit transportation and logistics on land and at sea. From a defense and intelligence perspective, quantum sensors could provide required, stable, and accurate measurements for our use on land, at sea, and in space. Quantum gravity sensors could assist in finding new energy and mining resources and detect underground facilities not apparent from visual examination.

[4] *https://coldquanta.com/coldquantas-latest-ultracold-technology-heads-to-the-international-space-station/*



ColdQuanta cold atom cells for several quantum applications.

Work has begun to use quantum sensing as antennae for radio frequencies such as those used in communications networks and cellular devices. We believe we can eventually manufacture smaller and more sensitive receivers that allow us to use more of the radio spectrum. For example, a ship, plane, or troops on the ground could have more compact communications systems with broader connectivity. In the U.K., British Telecommunications has already started trials of quantum RF technologies to augment 5G and presumably incorporate into 6G eventually.[5]

While it may seem more straightforward to focus only on computing, quantum sensors provide the *data* we will need to incorporate into processing at the Edge for commercial, intelligence, and military use. The data has the advantage that it is already encoded in a manner usable by quantum computers.

Being in the proper format does not mean we can move data where needed. The United States must invest in quantum interconnect technology to link quantum computers, sensors, and memory. Without the interconnects, we will restrict ourselves to building systems that cannot scale big enough or use data for the practical applications I have described above.

As I said at the beginning of this statement, quantum refers to Nature's structure and behavior at the smallest levels. Quantum technologies operate at the best resolutions possible. There is no higher resolution to go to than the quantum scale. There is no "next time" to get this right, to invest more aggressively, for the results and leadership we must have.

The call to action for skills and components

In what I think is a massive understatement, quantum is not easy. Programming a quantum computer is unlike writing software for a phone, laptop, cloud server, or supercomputer. Just as we teach classical programming in high schools today, we must extend curricula to include quantum. We must strengthen our education in computer science, physics, mathematics, and engineering if we expect to have a na-

[5] *https://newsroom.bt.com/bt-trials-new-quantum-radios-to-boost-next-generation-5g—iot-networks/*

tional workforce with the necessary skills to build and use quantum tech. We have made a good start at quantum computing education, but this must accelerate. We must extend physics and engineering education throughout our university systems to translate the science of quantum sensors into practical and ubiquitous products.

While we always need some people with the most advanced degrees at the leading edge, the quantum workforce will not be limited to those with doctorates. Just as today, we will need trained workers in manufacturing, I.T., and software and hardware engineering. There will be many new jobs and types of jobs, and we must have a trained workforce to fill them.

We must also secure our domestic supply chain. For many quantum modalities like ColdQuanta's cold atoms, we need increased access to lasers and rapid evolution of photonic integrated circuits. We must drive down the cost and size of these components. Only then can the United States ensure it can build the computers and sensors it needs.

Ensuring successful government, academic, and commercial collaboration

We appreciate your legislative support to reorient Federal spending and policy priorities to accelerate quantum development. Now is the time to guarantee we can execute the program. In particular, we require better procedural and program mechanisms to navigate the so-called "valley of death" stage of development, where we have scattered investment in and development of the pieces without integration into deployed systems of record.

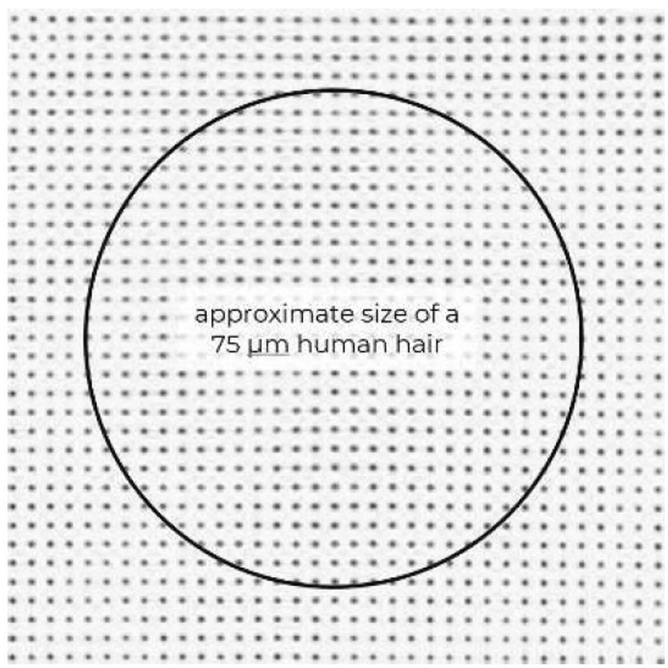


Image of actual ColdQuanta 1225 cold atom "pre-qubit" array at the University of Wisconsin

From where will quantum innovation come? To date, it has grown out of academia and been prototyped for government agencies but has only been commercialized by industry to a limited degree. Software is vital to making the quantum hardware usable, so in May, we acquired Super.Tech, a startup spun out of the University of Chicago. We must strengthen and accelerate the academia-government-commercial collaboration to get practical and pervasive quantum technologies in the next several years instead of the next several decades.

There is currently a shortage of Federal assistance to help small quantum companies transition their promising cutting-edge technology now under development to prototyping and then to production scale and capability. These are expensive steps that have sidetracked many promising advances in the past. We can't let that happen to the best-of-breed quantum projects now, given the stakes of losing to foreign adversaries. We need to do more to track, manage, and coordinate the many individual Federal quantum R&D projects across the government. We must ensure gaps are understood and covered, the most promising technology is fast-tracked and well supported, and overlaps and duplications are removed.

Thank you for this opportunity to highlight the quantum technologies that will be most valuable to the United States and to offer my recommendations to secure our leadership.

I am happy to answer any questions you may have.

Qualifications—Dr. Bob Sutor

How can I be so sure that quantum will change the world as I describe it? I am a 40-year computer industry veteran. I have an undergraduate degree from Harvard and a Ph.D. from Princeton, both in theoretical mathematics. In 2017, I became part of the leadership team of the IBM Quantum program after leading the 300-person IBM Mathematical Sciences Department for six years. I am the author of the quantum computing book *Dancing with Qubits* and the classical-quantum software development textbook *Dancing with Python.* I am a frequent keynote speaker at industry conferences. I have been quoted and interviewed in the Washington Post, the New York Times, the Guardian, Barron's, USA Today, CNBC, and many other media outlets.

I moved to ColdQuanta in March after 39 years at IBM because I believe the value of quantum technology extends far beyond the data center.

At ColdQuanta, Inc., we trace our roots back to a collaboration between two brilliant minds: Albert Einstein and Satyendra Nath Bose. In 1924, Bose sent a letter to Einstein and respectfully asked for his help. This correspondence sparked their uncovering of a new form of matter, later named the "Bose-Einstein Condensate (BEC)." When we cool atoms to a few millionths of a degree above absolute zero, they begin to clump together, condense into the lowest accessible quantum state, and transition from a gas into a BEC. However, this was speculation, as the technology needed to create BEC wouldn't exist for another 70 years.

In 1995, Dr. Eric Cornell and Dr. Carl Wieman created the first-ever BEC in Boulder, Colorado, at JILA—a collaboration between the University of Colorado at Boulder and the National Institute of Standards and Technology (NIST). Drs. Cornell and Wieman won the Nobel Prize in Physics in 2001.

ColdQuanta was co-founded in 2007 in Boulder, CO, by Professor Dana Anderson, an academic colleague of Drs. Cornell and Wieman. Since then, the company has built atomic clocks and quantum sensors, often in response to requests from United States agencies, including NASA, DARPA, and the Departments of Defense and Energy. Over the last four years, we have started the development of a quantum computer under the scientific direction of Professor Mark Saffman at the University of Wisconsin, Madison. We are a global company focusing on the United States and the United Kingdom. Our offices are in Colorado, Wisconsin, Illinois, and Oxford, United Kingdom, with additional employees in New York, Texas, California, and Florida.

ColdQuanta is committed to delivering broad quantum advantage through direct research and development of a wide range of quantum technology in collaboration with government and academia. We have become, in many ways, the foundation of a quantum supply chain and ecosystem. We are the only United States manufacturer of many key components for cold neutral atom and adjacent quantum research. We have two hundred employees, over 80 of which have PhDs in physics, engineering, mathematics, and computer science. We have 23 United States patents and many patent applications we expect to become patents with high probability in the next 12 months.

The CHAIR. Thank you. Dr. Sutor. Thank you so much. Dr. Jones, thank you for being here. I look forward to your testimony.

STATEMENT OF HENRY L. JONES II, PH.D., DIRECTOR, RESEARCH DEVELOPMENT AND SCIENTIFIC ENTREPRENEURSHIP, UNIVERSITY OF SOUTHERN MISSISSIPPI

Dr. JONES. Good morning, Chair Cantwell, Ranking Member Wicker, and members of the Committee. It is an honor to be invited to testify on this topic today. For the record, I am Dr. Henry Jones, Director of Research Development and Scientific Entrepreneurship at the University of Southern Mississippi.

Our nation has a strong base of institutions like ours that is a source of enormous competitive advantage, if we make the most of our diversity. I have experienced the opportunities and the challenges presented to us by our broad mosaic of a country. As an entrepreneur and investor, I have been a part of creating companies in Silicon Valley, in Chicago, and in Mississippi, and Alabama.

I was educated in the public school system of my small town of 1,000 in rural South Mississippi and at a public Mississippi university before moving West to Stanford University to earn a Ph.D. in aeronautics and astronautics.

I lived in Silicon Valley during the 90s dot com boom, inspiring me to start my first company. Using science developed in Mississippi State University lab, our Government's Landsat 7 satellite, and create cutting edge commercial products.

So from the start of my career, I have seen what academia and Government and industry can do together. What have we learned along the way? Government has had a tough time keeping up with the pace of technology. The people and processes of industry are built for competition with agile, lean, product market fit, and other concepts promoting quick iterations that are intensely customer driven.

The National Science Foundation has introduced these concepts with its I-Corp program that has spread to the National Institutes of Health and the Department of Energy. And the Department of Defense created the Hacking for Defense course at Stanford, which I have been teaching at Southern Miss.

USM has implemented these innovation approaches with our partners at NOAA, preparing its 55 petabytes of data for public customer driven analysis. I commend this committee for supporting the new NSF Directorate for Technology, Innovation and Partnerships, or TIPS, which I believe will accelerate the impact of these and similar programs. Unexpected innovations come from unconventional connections.

The latest data driven research and innovation is finding that cross-pollination of ideas from very different fields is how great leaps forward take place. EPSCoR, the established program to stimulate competitive research, enables this type of progress by bringing together universities and their individual innovators and exposing them to unfamiliar concepts in multiple ways.

Thank you, Senator Wicker, for your leadership by ensuring that EPSCoR States will receive an increase in NSF funding, which was the action needed to support continued geographic and economic diversity. In our economic system, the most important resources are customers and capital.

This committee was on target with the CHIPS and Science Act, in particular the creation of regional tech hubs to promote the conditions for new concentrations of these important resources. Thanks to you, Senator Wicker, and your colleagues here, one-third of the new 8 to 18 new hubs will include EPSCoR States as a coalition member, and that matters.

I have been a Mississippi tech executive pitching for capital on Sandhill Road, where those investors expected us to move to Silicon Valley as we grew. As these tech hubs are created, special consideration should be given to the alignment of capital pipelines, from angel to venture, or else the future tech hub success stories will feel that same gravitational pull. Diversity is a national resource for resilience.

The tech industry sees the competitive necessity of a diverse workforce. Conforming cultures lead to groupthink and being blindsided by unconventional ideas. Companies are seeking diversity in every dimension it can be achieved, yet are struggling in the most significant area, enough trained U.S. citizens.

I am sure we have enough capable U.S. citizens, but we are missing something in the early stages of the educational pipeline. There are generational and socioeconomic barriers to STEM futures that can feel insurmountable. Our university has recently modified our computer science curriculum to incorporate industry certifications as milestones within our degree programs in case a student can't put 4 years of courses together at once.

Academia has more innovation that we can do. My biggest fear in regard to securing our leadership in these technologies is that instead of applying the energy and resources to accelerate, that we coast instead. Like a race car driver seeing open road ahead but with no rearview mirror, we won't know that our competition has passed us until they are out in front. Even then, it takes time to accelerate and catch up if we can.

This hearing, the CHIPS Act, EPSCoR, and the NSF TIP Directorate are the right things to do for us to accelerate now. Thank you again for this opportunity to speak with you.

[The prepared statement of Dr. Jones follows:]

PREPARED STATEMENT OF HENRY L. JONES II, PH.D., DIRECTOR, RESEARCH DEVELOPMENT AND SCIENTIFIC ENTREPRENEURSHIP, UNIVERSITY OF SOUTHERN MISSISSIPPI

Good morning Chair Cantwell, Ranking Member Wicker, and members of the Committee. It is an honor to be invited to testify on this topic today. For the record, I am Dr. Henry Jones, Director of Research Development and Scientific Entrepreneurship at the University of Southern Mississippi (USM).[1] Like most of the 3,000 four-year universities around our country, USM serves local, regional, national and global constituents through our bright students and dedicated faculty and staff. Our nation has a strong, diverse base of institutions like ours that is a source of enormous competitive advantage—if we make the most of it. If instead our policies promote a narrow-minded approach that directs attention to a few big brand name institutions, this national advantage disappears and we lose the resilience of our country's diversity.

I have experienced the opportunities and challenges presented to us by our broad mosaic of a country. As an entrepreneur and investor I have been a part of creating companies in Silicon Valley and Chicago—and in Mississippi and Alabama. I was educated in the public-school system of my small town of 1000 in rural south Mis-

[1] *https://www.usm.edu/*

sissippi and at a public Mississippi university—before moving west to Stanford University to earn a Ph.D. in Aeronautics and Astronautics. I lived in Silicon Valley during the 90s Dot Com boom, inspiring me to start my first company using science developed in a Mississippi State University lab and our government's Landsat 7 satellite to create cutting-edge commercial products for foresters. From the start of my career, I have seen what academia and government and industry can do together.

What have we learned along the way?

Government has had a tough time keeping up with the pace of technology. The people and processes of industry are built for competition, with Agile, Lean, Product/Market Fit, and other concepts promoting quick iterations that are intensely customer driven. The National Science Foundation (NSF) has introduced these concepts with its I-Corps program [2] that has spread to the National Institutes of Health (NIH) and the Department of Energy (DoE), and the National Security Innovation Network (NSIN) [3] within the Department of Defense (DoD) created the Hacking for Defense (H4D) course [4] at Stanford which I have been teaching at Southern Miss as Designing Solutions for Defense (DS4D).[5] USM has implemented these innovation approaches with our partners at the Coastal Data Development program within the National Centers for Environmental Information at NOAA,[6] preparing its 55 Petabytes of data for public, customer-driven analysis. I commend the Committee for supporting the new NSF Directorate for Technology, Innovation, and Partnerships (TIP),[7] which I believe will accelerate the impact of these and similar programs. I was on a call earlier this week with Jason Calacanis,[8] one of the most successful Silicon Valley investors in early stage companies, and he listed areas like healthcare and hardware where startups struggle greatly for funding due to bureaucracy and insufficient basic research. I recommend that TIP's Assistant Director Gianchandani contact Mr. Calacanis and other startup experts, to ask for suggestions for how the NSF can change that math.

Unexpected innovations come from unconventional connections. The latest data-driven research in innovation is finding that cross-pollination of ideas from very different fields is how great leaps forward take place. EPSCoR,[9] the Established Program to Stimulate Competitive Research, enables this type of progress by bringing together universities and their individual innovators and exposing them to unfamiliar concepts in multiple ways. Thank you, Senator Wicker, for your leadership by ensuring that EPSCoR states will receive an increase in NSF funding, which was the action needed to support continued geographic and economic diversity. I believe in this program, too—I serve on a statewide EPSCoR board because it makes sense for our universities to work together. What I observed is that the real potential of EPSCoR is its creation of new relationships, better communications between institutions at the faculty level, and policy changes that align incentives for working together, all to create a long-lasting environment of unconventional collaborations.

In our economic system, the most important resources are Customers and Capital. For this reason, a few large urban areas are understandably attracting more than their share of each. This Committee was on target with the CHIPS and Science Act, in particular the creation of Regional Tech Hubs, to promote the conditions for new concentrations of these resources. Thanks to you, Senator Wicker, and your colleagues here, one third of the 18 new Hubs will include EPSCoR states as a coalition member, and that matters. I have been a Mississippi tech executive pitching for capital on Sand Hill Road, where those investors expected us to move to Silicon Valley as we grew. As these Tech Hubs are created, special consideration should be given to the alignment of capital pipelines, from angel to venture, or else the future Tech Hub success stories will feel that same gravitational pull. Similarly, the Hubs should consider the presence of customers as the driving force for technology adoption, not the location of the technologists, possibly creating 'virtual hubs' for certain types of problems like cybersecurity where the customer environment is primarily online.

Diversity is a national resource for resilience. My friends at the big tech giants like Microsoft and Amazon tell me that those organizations have seen the competitive necessity of a diverse workforce. Conforming cultures lead to groupthink and being blindsided by unconventional ideas. These companies are seeking diversity in

[2] *https://beta.nsf.gov/funding/initiatives/i-corps*
[3] *https://www.nsin.mil/*
[4] *https://www.nsin.mil/hacking-for-defense/*
[5] *http://ds4d.usm.edu*
[6] *https://www.ncei.noaa.gov/*
[7] *https://beta.nsf.gov/tip/*
[8] *https://www.linkedin.com/in/jasoncalacanis/*
[9] *https://beta.nsf.gov/funding/initiatives/epscor*

every dimension it can be achieved, yet are struggling in the most significant area—enough trained U.S. citizens. I am sure we have enough *capable* U.S. citizens, but we are missing something in the early stages of the educational pipeline. One of my childhood friends is a fourth-generation logger, yet his son is a natural with computer programming—he's a proud nerd. This family doesn't know what a STEM career looks like or how to afford a technical education. Luckily we now have him on a path to maximize his innate skills and interests, but through this experience I'm discovering that there are generational and socioeconomic barriers to STEM futures that can feel insurmountable. Our School of Computing Science and Computer Engineering[10] at USM has recently modified our computer science curriculum to incorporate industry certifications as milestones within our degree programs, in case a student can't put four years of courses together at once. The Center for Military Veterans, Service Members, and Families at USM[11] introduces veterans to resources within higher education, and also prompts the academic community to make changes to welcome these high potential students who aren't coming directly from high school. Academia has more innovation we can do.

My biggest fear in regard to securing our leadership in these technologies is that instead of applying the energy and resources to accelerate, that we coast instead. Like a race car driver seeing open road ahead but with no rear-view mirror, we won't know that our competition has passed us until they are out in front. Even then, it takes time to accelerate and catch up—if we can. This hearing, the CHIPS Act, EPSCoR, and the NSF TIP Directorate are the right thing to do—we need to accelerate now. Since I started college 30 years ago, every year I have shared classrooms and workplaces with international colleagues—hard-working, curious, and intelligent. We are all familiar with our trade imbalance, but what about our insight imbalance? Do we have widespread knowledge of what China is doing and can do, in the same way they know about us? Could one of the programs mentioned above, or another one, start sending U.S. citizens to China in much larger numbers to begin to learn from them? That would be the wise action of a leader who wants to stay ahead. How do we get a very clear image in our rear-view mirror, and confidently step on the gas?

Thank you again for this opportunity to speak with you today.

The CHAIR. Thank you, Dr. Jones. We will now go to a round of questions, and I am going to ask my questions first and then turn it over to Senator Hickenlooper to chair the rest of the meeting. And I appreciate his leadership at the Subcommittee level.

Dr. Albritton, obviously one of the things we need to do to further our efforts here is the $13 billion that was authorized for NSF Foundation STEM education efforts. And as we have passed previous COMPETES Acts, what has happened, circumstances, you can say the downturn of the economy and we didn't fully fund the competition bill. So how do we explain to people the need for these STEM dollars?

And second, you mentioned the areas of NSF expertise you are already involved in as it relates to these computational sciences. The bill was all about translational science. It was about a new directorate to translate science faster. Can you explain what are the testbed needs of, an example the University of Washington, to actually help us combine both the workforce and the infrastructure that is needed to do the translational science?

Dr. ALBRITTON. Absolutely. I will start with the first question about, I believe, explaining to the public about our workforce needs and how we need to fund this, if I have it right, Senator Cantwell. I think, you know, look at me, I grew up in Louisiana.

So having the opportunity as a young person to understand the excitement of science and engineering. If you look at my career, I have been to ping pong in that area, but make sure we inten-

[10] *https://www.usm.edu/computing-sciences-computer-engineering/*
[11] *https://www.usm.edu/military-veterans/*

tionally tell young people, hey, this is for you, this is an exciting area, you can have a future. Tell their parents too this is for their children.

They can grow and become great contributors to the U.S. economy. So I think starting early but then making the opportunities available. You know, we hear about college costs, for example. But as we bring in these more diverse groups of people, I think there should be funding to make sure that they succeed and prosper.

So programs that support our students as they come into the universities, ensure that every one of them graduates, has interactions with industry so that they can see their future and prosper. So those are some of the——

The CHAIR. Well is it safe to tell our appropriator colleagues who may look at this authorization and then decide to pass that they are going to fumble the ball?

Dr. ALBRITTON. Yes, they will fumble the ball. And we have already heard from my colleagues that other countries are out in front of us. If you look at the numbers of students going into STEM, it is far lower than we need. In the State of Washington, we don't have the capacity even for the students that want to.

We cannot fumble this ball. It is a global competition. We don't want to lose this competition. And we need everyone moving forward and playing on this football field, so to speak, so that we have got all the brainpower in the U.S. moving us toward the goal post.

So I think yes, we would have fumbled badly if we don't want to invest, make sure we have good educational support systems for our students so they can see themselves succeeding in engineering and science, and then put in the necessary infrastructure and support systems so that they grow as students and they actually graduate and prosper.

The CHAIR. So on the translational science part, what are the things that we need to get test labs still established?

Dr. ALBRITTON. Yes, so test labs. So our vision at the UW is to have open, accessible regional hubs. And let's talk about quantum. Very, very expensive technology. State of the art systems are cooled to almost absolute zero, very environment sensitive.

The National Quantum Initiative funded some regional large areas, but it would be truly great to have qubits for our students to come and interact with, for example, where they can learn the quantum foundations, technology. They can just get really jazzed up because of what they have just done by flipping a qubit or something.

So we want regional hubs that have state-of-the-art infrastructure for education, workforce development, even people that are already out beginning their careers, pulling them back to reeducate them for this new emerging area. And then also testbeds that have state-of-the-art characterization tools, et cetera.

So researchers don't need monumentally huge grants, but they can go into this regional facility that is easily accessible and do their wild and crazy ideas, their innovative thinking. So all of these, I think, on these regional hubs would really lift the U.S. quantum ability.

The CHAIR. Well, thank you for that. I think we are going to have to explain to our colleagues on appropriations exactly how the other aspects.

There is already some foundation in the bill for us to do the testbeds, but we have to show them that this is a combination of both. So, thank you. Again, thank you to Senator Hickenlooper for chairing the rest of the hearing.

Senator HICKENLOOPER [presiding]. Great. Now we can really get started—just kidding. I get the privilege of calling on the Ranking Member to ask some questions, and just I will preface that just make sure everyone is aware that he has been one of the great champions in the U.S. Senate in terms of maintaining American leadership in innovation and science. Senator Wicker.

Senator WICKER. Well, thank you very much, Senator Hickenlooper and Madam Chair. Mr. Breckenridge, tell us—defend your statement that Mississippi State is a national leader in high performance computing. And when this EPSCoR expansion sunsets in 2029, do you have any doubt in your mind that the leadership of this country, whoever it is at that point, will conclude that this was an excellent decision and should be made permanent?

Mr. BRECKENRIDGE. Well, as I stated, MSU has been involved in high performance computing for quite some time. We developed our first computing cluster system in the late eighties, well before this technology became the standard that it is today that most supercomputers are built utilizing.

We have developed the software stacks that enable high performance computing and message passing interface, software middleware developed at MSU in partnership with the Department of Energy and Argonne National Laboratory.

We pioneered many of the technologies that are used for high performance computing communications, from early in the 90s with Marinette Technologies, these high bandwidth low latency interconnects, to the standards that are viewed today in InfiniBand.

MSU has been a leader in that technology. We have also excelled in the use of high performance computing. It is not just building these systems and designing them, it is actually utilizing them to advance science.

So MSU is widely viewed as the leader in grid generation, and we are doing huge amounts of work today in autonomous vehicle work and in weather modeling and cybersecurity and so many other areas that are heavily dependent upon high performance computing.

Senator WICKER. Thank you. And I just wanted to give you the opportunity to say to the rest of the country, those people that are listening and that will be reading the transcript, that you are a national leader there, in the small town of Starkville, Mississippi, and not some land grant outpost that is trying to grab a little Federal money.

Let me turn to Dr. Jones. This EPSCoR, 20 percent goes back to 13 percent or so in 2029. Are we going to be able to defend this decision? Any doubt in your mind about that?

Dr. JONES. Yes, sir. I believe in an EPSCoR program like you do—[technical problems]—I believe, sir, in the EPSCoR program like you do. So much so that I serve on a statewide EPSCoR board as an industry member. I think I was chosen because I have relationships with all of the statewide research institutions, and I knew that it was imperative that our universities work together.

And we will see the results of that collaboration, not necessarily in the technology that is developed because that is hard to predict, especially on the front end. What we will see in the long term are new relationships, better ways to communicate, changes in policy that align incentives across the universities to work together.

And so consequently, we will have long lasting collaborations of these new sorts that I mentioned earlier.

Senator WICKER. I just think the results that we produce out of this increased research across the length and breadth of our country is going to be recognized. Can you take a few seconds and tell us about the virtual hubs that you mentioned in your testimony?

Dr. JONES. Sure. So one of the things that I think that we can tend to do is we operate like things have always been instead of thinking about having a vision for how they might be. And so we could connect people when they are most—they are closest geographical neighbors, because that is the way that we would often done it in the past.

But we could connect our EPSCoR neighbors because of the nature of the expertise that is underlying their ability to put new technology together, to bring customers to the table, to pull—to create partnerships, to communicate well.

So a virtual hub might not look like the hubs of the past in the same way that our response to the pandemic has allowed us to use virtual connections and to meet online as normal as it is to meet in person. We can use that same change in mindset to connect our EPSCoR States around the country.

Senator WICKER. Well, it seems that my time has expired, but if the Chair would indulge me. Mr. Clark, your virtual intelligence didn't have to be too smart to conclude that you were really keen on the National AI Research Resource, but it did include it in the conclusion. For those of us who didn't make an A in chemistry and majored in the liberal arts instead, can you help us understand why that is so important and what it is?

Mr. CLARK. Absolutely, Senator.

Senator WICKER. And minus one minute.

Mr. CLARK. Yes. The National AI Research Resource is an attempt to create a shared infrastructure, a big computer that academics around America can access to put them on a level playing field with the private sector.

One of the ways that we hire people at my company, Anthropic, is we find people from Tier I research universities and one of the incentives we can offer them to join us is we have more computers than them.

And I don't think we should necessarily have more computers than MIT or Stanford or Harvard or really any large scale research university. I think that that is why you lose academics, and you lose the teaching base.

So we need to do something to keep these people there and let them do experiments close to the ones being done in industry and then we can all learn from their insights.

Senator WICKER. Thank you. And thank you for your indulgence, Mr. Chairman.

Senator HICKENLOOPER. Great. Again, I want to thank you all. Already, I think you all have displayed a lot of the rationale behind why we so excited to get you all together here. I want to start with Dr. Sutor, and we are—there are a number of hubs for quantum computing. Old—-CU Boulder and NIST have had a partnership dating back to the 1960s and put together the JILA.

Obviously we are going to need—one of the benefits of those partnerships is helping create the workforce. I think almost all of you have alluded to the importance of maintaining a diverse and qualified workforce. How can we expand workforce and educational opportunities in quantum computing?

We have heard about the expense of creating these hubs. And what can we look—what can we learn from the success of CU Boulder's ecosystem in that regard?

Dr. SUTOR. Well there are two main points to make there. And so first starting with Boulder. There was tremendous insight, as you said, in 1960s between the Government through NIST and CU Boulder to build JILA, which was actually originally about astronomy but is now the most precise atomic clock in the world, is in Boulder, Colorado, developed there.

So a tremendous amount of core science there that spills over, of course, into the education, many opportunities for undergraduates and graduates. But then companies come out of that. There was a celebration yesterday of a startup company that was founded by people originally at JILA.

So these three axes of academia, Government, eventually leading to commercial success. Now, the other examples are Colorado School of Mines, which recently put together a program on quantum engineering. We hear a lot about quantum information theory and quantum science.

We should talk much more about quantum engineering because that is translating it to implementation. It is a multidisciplinary program. It is mathematics. It is physics. It is chemistry. It is computer science as well. We have to create very practical and complete systems that work.

As odd as it may seem, we can distribute our investments, but ultimately we need working systems, and we need people who can use them. As I said in my statement, there are going to be many new types of jobs, jobs that we don't even know the names of yet. Quantum computing will go beyond classical computing.

So these jobs are not simply replacing what we have already. We are going to need the tens of thousands of new jobs on top of everything we have now.

Senator HICKENLOOPER. All right. Great. I appreciate that. And I have more questions, but I want to rotate my way—I at least will be here for a second round of questions. I can guarantee you all that.

Dr. Clark, experts have said that there are 20—up to 21 different standards of fairness in terms of trying to work through this in regards to artificial intelligence. Public and private sector entities often build their custom processes as a competitive advantage to ensure fairness in a particular domain.

How can we start beginning to aggregate, to concentrate around agreed common definitions of what fairness—and fairness is one of the most closely held moral values among most Americans? Why is it so important that policymakers start to align fairness policies?

Mr. CLARK. Thank you, Senator. There is a good example already to emulate the work NIST does today. It has a test called the facial recognition vendor test, which tests out facial recognition systems along a whole bunch of axes that test for fairness and bias.

And what NIST did is took a whole bunch of different industry standards and approaches in academia and industry and pushed them together into one test that it worked on in partnership with a bunch of people.

And we need to do something similar for AI, where we need to find a way to take all of thinking happening in academia and industry and find a central place where we can work through these issues and arrive at a test or set of tests that we feel is fair and representative.

I would love for that to be a race to the top on fairness in industry, and I think we can unlock that if we create this kind of test.

Senator HICKENLOOPER. You and me both. Let's see, I was going to have—ask, where was that question? Ah, Dr. Jones, the—AI powers smartphones, features digital assistants, real time translation, a lot of those things.

The future of AI is going to need more R&D to incorporate context relevant to the task at hand. What are some examples—other examples of functions that AI could better perform if it could better understand the intentions, the tone of cultural cues behind the voice command?

Dr. JONES. Well, that is a great question. I think that maybe, frankly, Mr. Clark might be a better——

[Laughter.]

Senator HICKENLOOPER. I think that is fair enough. You know, one thing about a truly expert staff is they will gravitate toward the right answer for a different question. I am sure we will come back to Dr. Jones as well.

Mr. CLARK. Could you just quickly restate the——

[Laughter.]

Senator HICKENLOOPER. Asking about the importance of cultural cues, tone, intentions in terms of what were some of the examples of functions that AI could do better if, you know, if it could understand those cues? You know, chime—you know, voice instructions.

Mr. CLARK. Yes. A way to think about this is the reason why we need more testing by a broader set of Americans is for, as you build these tests, you learn how to reflect the values of a greater set of people. AI currently reflects the values of large amounts of data found on the Internet and some of the companies that build it, which isn't representative of all Americans.

And so we can find ways to bring a much larger set of people into the testing and evaluation of these systems. And then you can kind of bacon that cultural background knowledge so these systems are more representative and more cues to the subtleties of our particular culture.

Senator HICKENLOOPER. All right. And Dr. Jones, I didn't know, are you are originally from—you are not from Mississippi originally?

Dr. JONES. I am actually from, originally from Mississippi. I had a feeling that Mr. Clark was not.

[Laughter.]

Dr. JONES. Thought he might be best at answering that question.

Senator HICKENLOOPER. Well, I thought—again, we will come back to this. I am out of time, but the—I think the lilt to your voice which gave away, despite all the Stanford education, gave away Mississippi origin, that that is one of the big issues in terms of figuring out how do you get this, some sort of standardization. Anyway, I will come back on the second round and now recognize Senator Blackburn who is with us remotely.

STATEMENT OF HON. MARSHA BLACKBURN, U.S. SENATOR FROM TENNESSEE

Senator BLACKBURN. Thank you, Mr. Chairman. And indeed, another Mississippi voice. And I am glad to see that we have someone from Mississippi State on the panel today. That is my alma mater. So good choice there. Mr. Breckenridge, let me come to you for our first question.

Oak Ridge National Labs in Tennessee, they are home to the Frontier, which is the fastest computer in the world, and it is capable of executing 1 quintillion FLOPS per second, and it has allowed the U.S. to enter the exascale computing era. And this is unlocking tremendous potential.

We are really so proud of the team that is working on this. But if you would just touch for a moment what supercomputing and quantum technologies will unlock, what economic and benefits that you expect to see coming from this, and then talk touch on the downsides, whether they are economic or otherwise, of the U.S. losing the quantum race?

Mr. BRECKENRIDGE. Thank you, Senator. Yes, absolutely, the number one system in the world is at Oak Ridge National Laboratory, as you indicated. The U.S. must—we must put more focus into developing and giving access to these systems to a broader set of our research community.

The systems that are available now to the traditional university are an order of magnitude smaller or maybe many orders of magnitude smaller than that of the—at Oak Ridge National Laboratory.

This is a focus that we have to work on, not only from a technology standpoint, but from a workforce standpoint as well. And if you don't mind, would you repeat your second question?

Senator BLACKBURN. Well, what are the downsides? You know, I think we know of some of the benefits, and I am pleased that you mentioned the workforce because since not everybody has access like the students at University of Tennessee who are partnered with Oak Ridge and who are working Frontier, I think that that is one of the downsides. But also, I want you to talk about what you see is the downsides if we lose this race, this quantum race.

Mr. BRECKENRIDGE. Oh, losing the quantum race has a huge downsides from a national security standpoint to being able to do advanced technology. So I think it is something certainly we are unable to lose. It is just not an option for us.

Senator BLACKBURN. OK.

Mr. BRECKENRIDGE. The—from the benefits of HPC and quantum, you know, those are many. Whether that is making safer vehicles or doing a better job in predicting say where hurricanes may impact us.

This is certainly something that we are facing now. If we are able to see and develop a better model of where these hurricanes would make landfall, we could save lives and increase our responsiveness to that, and to that point, minimize the economic impacts to us as much as we can.

Senator BLACKBURN. Well, and I think we all know that having quantum technologies will open the door for so many things with logistics, with blockchain, with cryptocurrencies, with supply chain. Mr. Sutor, I want to come to you on the supply chain issue. There has been a lot of discussion about semiconductors, and we have heard about that today.

We have heard about, and we are seeing some of the worst supply chain issues that we have ever had. So, what—how is that prohibiting what your company is doing? And how severely do you see this impacting the growth in this technology sector for our country as we face these supply chain constraints?

Dr. SUTOR. Well, Senator, first of all, so when we speak about quantum computing, it is an integration of classical computing as well as this new technology. So any problems we may have with supply chain, with classical computing, such as semiconductors, will spill over into our inability to do things with quantum.

But there are some new technologies such as photonics, photonic integrated circuits, as well as lasers. With ColdQuanta, we sometimes say we shine lasers at very tiny things, and those are being atoms. Well, we need many atoms, many qubits, ultimately tens of thousands or millions of those.

We need extremely robust laser technology that we can get when we need it. We have to scale these things down. You can't have 10,000 lasers just to do a little bit of computing. So we need advanced technology and development, domestic technology on these so-called photonic integrated circuits.

Think of semiconductors, but instead of pushing electrons around, we are pushing around photons of light. Many other countries have developed photonics centers. I believe the Netherlands have invested over $1 billion in photonics as well. Are we happy enough to get these sorts of essential supplies from outside our borders?

So I believe a systematic examination of the different, not just quantum computing, but quantum sensing modalities, the constituent parts are a necessary, identification of where they come from, and can we provide those ourselves? But for us, it is photonics, and it is lasers.

Senator BLACKBURN. Thank you. Thank you, Mr. Chairman.

Senator HICKENLOOPER. You bet. Thank you. Now let's switch to Senator Klobuchar, again remotely.

STATEMENT OF HON. AMY KLOBUCHAR, U.S. SENATOR FROM MINNESOTA

Senator KLOBUCHAR. Thank you very much. Thanks for holding this hearing. Very important. My state brought to the world everything from the pacemaker to the Post-it note, and like every other State, we are facing workforce issues. I know that this has come up already in the hearing.

Dr. Sutor, in your testimony, you mentioned that the future quantum workforce will not be limited to those with doctorates, that we need trained workers in manufacturing, IT, hardware engineering. What are some of the trained skills we are going to need in our next generation? And if you could be brief, I have got a lot of questions.

Dr. SUTOR. First, computer science. The best classical computer scientist or software engineer could be a terrible quantum computer scientist or engineer. It is really so radically different that we have to start at the very lowest levels, and in high school, for example, for this training.

We must make sure that we don't just focus on the sciences, we focus on the practical. We are going to need to manufacture these components. These are new techniques, and these are the types of skills and jobs we are going to have to educate.

Senator KLOBUCHAR. OK. Thank you. Mr. Clark, researchers in my home state at Mayo in Rochester have partnered with universities and data science specialist to use artificial intelligence to process incredibly complex clinical data to uncover causes of everything from cancer to childbirth options for expectant moms. In your testimony, you highlight the significant role artificial intelligence will have in improving health care. How can we facilitate these partnerships?

Mr. CLARK. One of the best ways to facilitate partnerships here is to take out some of the complications involved in handling this very sensitive data. And the reason I have referred to the National AI Research Resource so much is it can prove to be a place where we can prototype new governance systems that are both sensitive to HIPPA but make it easier for a broader set of researchers to access medical data.

You know, bring the data to where a large computational system is so you can train breakthrough systems. And bring as many universities and hospitals together in a partnership so you can make sure that the systems you train are fair and representative and will work on different populations across America.

Senator KLOBUCHAR. Very good. I think another area that, actually Senator Wicker and I have a bill, on this, Precision Ag Connectivity Act, another area where we are going to see this, and I know you mentioned it in your testimony, Mr. Clark, is an Ag with best leveraging technologies to be able to—AI technologies to be able to do everything from figure out how much water they need, we could save a whole bunch of water, to planting and other things.

So I am not going to ask any question on that because I want to, in my remaining time, move on to a few of the challenges we have. And you, Mr. Clark, I will ask you this. We need more transparency when it comes to the recommendation algorithms that most Americans encounter in their social media feeds every day.

Senator Coons and Portman and I have teamed up on the Platform Accountability and Transparency Act to require digital platforms to give independent, verified researchers access to data with appropriate privacy protections.

You recommend that the Government invest in the measurement and monitoring of artificial intelligence development. Can you tell us what kind of information and resources a researcher like yourself would need in order to fully evaluate how an AI system would affect users?

Mr. CLARK. Thank you, Senator. The primary thing you need to do is give them access. You need to give them access to the system and the ability to run tests on it. And I will give you just a concrete example. I work with AI systems that are made of billions of parameters, billions of things that we need to understand.

Recommender algorithms these days have trillions of parameters. So the time to invest in this and bring researchers to this is right now. You need to give access to the system. You need to let them run experiments, and you need to find a way that not just companies control access to that, but researchers are able to, even if they find uncomfortable things, continue that research so we can have that discussion.

Senator KLOBUCHAR. Very good. And also in your testimony, you highlight the importance of that shared public research infrastructure with the National AI Research Resource. How can supporting and NAIRR is helping create leadership in these emerging industries?

And again, Senator Lummis and I actually have a bill along these lines with the social media platforms to get at some of the work that needs to be done with these companies. Could you answer that quickly? And then I can—you can move on to my colleagues.

Mr. CLARK. Yes, I will be very brief. In my oral testimony, I compared some of these modern AI systems to Swiss Army knives. They are actually more complicated than that. They are like Swiss Army knives where you don't know all of the things the knife can do until you have built it and spent a lot of time testing it.

So the reason why you need a National AI Research Resource is so researchers can train and develop some of these systems on par with the opaque ones and industry and work out what all the capabilities are, and which ones need sort of regulations and which ones are just very exciting and can be used in the economy.

Senator KLOBUCHAR. All right. Well, very good. Thank you to all the witnesses. Appreciate your work.

Senator HICKENLOOPER. Thank you, Senator Klobuchar. And now I get to call on our Ranking Member. This actually started within the Subcommittee, the Space and Science Subcommittee, which I Chair, but really Co-Chair with Senator Lummis from Wyoming.

STATEMENT OF HON. CYNTHIA LUMMIS, U.S. SENATOR FROM WYOMING

Senator LUMMIS. Well, thank you, Mr. Chairman. This—being on this committee is like a wicked indulgence, because we get to ask you questions, some of the most cutting edge, brilliant people in our country. And as I looked at your bios, I am just extremely impressed with your capabilities.

Dr. Albritton, I have a question for you that I am going to start with, and then I want to go to Mr. Lupien, who is at the University of Wyoming. Dr. Albritton, I am interested to hear about projects in your specialty that you are working on. You have such an impressive background.

Dr. ALBRITTON. Are you—me, personally, or the University of Washington?

[Laughter.]

Senator LUMMIS. Well, either or both.

Dr. ALBRITTON. So me personally, I am a biomedical engineer, by the way, but I advocate for the entire college. And I can give a wonderful example about how AI needs more cultural context. I work on digestive diseases and the intestinal track. Google is always offering me digestive aids and other remedies because it can't distinguish what is research and what is an actual physical problem.

So that is what I do and a lot of entrepreneurship. But my major job now is really as chief advocate for the College of Engineering. And the fabulous part is I get to learn. As you said, it is wickedly fun. I learn about quantum information. I learn about great battery storage. We have a new technology.

Senator Cantwell was talking about our test bed facility called QT3 that we are trying to roll out at the University of Washington, where anyone can come in and play with a qubit. The students can.

It is just amazing fun and excitement to learn about other things like our AI centers, AI for social good, really trying to make our technology benefit humankind, lead to—allow people to live better lives. It is just a super fun job, so thank you.

Senator LUMMIS. Yes. This is an outstanding panel and a great subject. I want to turn to Mr. Lupien. Thank you for joining us today and representing some of the cutting edge work happening at the University of Wyoming, my alma mater.

I want to start by asking you to explain distributed ledger technology and how it can be used in many different industries and sectors. And also, could you take us into what you see as the future of distributed ledger technology?

Mr. LUPIEN. Well, thank you, Senator. That is a very big question for a couple of minute answer. Distributed ledger technology, as I mentioned in my testimony, is really just a new type of data base. Unlike my colleagues on the panel who are dealing with high performance computing applications in quantum and AI, blockchain is actually not a high performance computing application.

It is an applied application that will touch pretty much everything that we do in our daily lives, very much like we are experiencing today with the internet. And where we are going to see the future, Senator, I believe, is how value is going to be moved much more easily electronically around the world.

And, you know, we are going to be able to move value almost instantly and with the settlement finality that doesn't exist in our existing financial systems today, which are based on, you know, netting balance sheets to move value. We know we are going to move actual value. And where I really see the future, Senator, is how digital assets are going to drive some new technologies such as the metaverse.

And, you know, within the metaverse, which is the way I basically describe it is, you know, kind of the Internet on steroids. It is going to be an immersive use of the internet. Well, digital assets are going to drive that—drive that technology. It is how we are going to be paid within the universe. It is how we are going to buy things within the metaverse.

And so I think that is the exciting part of where this is going. But, you know, blockchain technology itself is kind of in its, you know, entering its bread and butter stage where, you know, it will be doing a lot of things for consumers and industry and our financial services industry, where we don't even realize that that technology is what is driving the back of the house.

So, I hope that answers your question, Senator Lummis.

Senator LUMMIS. Thank you. And I have only 5 seconds to spare, so I will yield back. But if there is another round, I find this a fascinating panel, and I want to thank you all for taking the time to be here.

Senator HICKENLOOPER. I suspect there will be—I know there will be a second round because I am not leaving. So, Senator Baldwin.

STATEMENT OF HON. TAMMY BALDWIN, U.S. SENATOR FROM WISCONSIN

Senator BALDWIN. Thank you, Mr. Chairman. It is been wonderful hearing all my colleagues boast about the incredible assets in their states. I certainly don't want to pass on my opportunity to recognize that the University of Wisconsin-Madison was the first university in the country to establish a professional master's program in quantum computing.

We also are home in the state to a now Hewlett Packard Enterprises, Cray, which has been very involved in supercomputing and exascale supercomputers, and we hope we will have a role, very prominent role as we imagine and move to quantum.

So I wanted to start, by the way, recognizing Dr. Sutor that ColdQuanta has a Madison, Wisconsin office and we are very pleased to be host of that. What I wanted to start with is, given the passage of the CHIPS and Science Act, and there are lots of references to appropriations continuing that drive, I will say I am one of the appropriator members of the Commerce committee, so I am listening very carefully to that.

But there is this momentum federally to accelerate quantum tech transition through the, how can we have it go through the valley of death, as you were describing in your testimony, and into commercialization? What sort of—how can we use the opportunity of this momentum right now?

Dr. SUTOR. Let me reiterate, we are very happy to be in Madison. When ColdQuanta decided to in fact start its quantum computing effort 4 years ago, we turned to Dr. Mark Saffman in the physics department.

We have about 25 employees there, many of whom were trained out at University of Wisconsin as well. So it has been a great asset for us. When we talk about new technologies, they are often created by small companies. Yes, some of the big ones invest sometimes startups.

Unfortunately, 90 percent of all startups fail. And I keep researching this number year after year, and it keeps coming up that 90 percent of all startups fail. And so one fundamental question is, are we willing to let 90 percent of all the great new technology, particularly in quantum technology, which I think we can all agree is necessary for our future, are we willing to have a 10 percent success rate of moving out of the laboratories, the academic laboratories into commercial production?

So what we do need from the Government is support for longer term investment to keep these companies going, to get them to partner with other smaller companies, to systematically evolve this technology into something that works. That is a good thing. But that we can manufacture, which is often a very different question as well.

So this is that valley of death that I spoke about, to go from great idea to actually manufacturing and selling hundreds of thousands, tens of thousands and that is where we need help from the Government.

Senator BALDWIN. Yes. And in a number of these cases, the Government will be the ultimate consumer, I would imagine. Think of the various examples that have been given in weather prediction or defense applications, communications. So you know that is certainly an opportunity. Let me continue on.

In 2017, China demonstrated an ability to utilize what is called a "quantum repeater" to distribute information across great distances between Earth and space. This technology will eventually enable secure transmission of information not susceptible to eavesdropping. And in reality, China is likely much more advanced in this space than their published work might suggest.

Unfortunately, competing with China is not only going to be just about achieving the next technological breakthrough or demonstration. We have to ensure that we also have the organic manufacturing base available to support large scale commercialization for technologies that have serious security implications like quantum networking, but also for quantum sensing that will be key for future GPS and satellite architectures.

So, Dr. Sutor, what areas of the industrial base do we need to be focusing on for the raw components and material that we will need to maintain a future quantum manufacturing edge over China?

Dr. SUTOR. As we have spoken about quantum computing, we have focused on the processing. So that is like thinking of your laptop and just thinking of the processor, but not the data. The data is critical and that is what comes from quantum sensors. That is what is transmitted in quantum networks.

So for one, I think we need to turn around a lot of our considerations and look at a data first view of what we are doing with quantum. In the case of quantum networking, the repeaters, we need quantum memory, something which we really do not know how to do very well at all.

So as we go through and look at all the quantum technologies such as memory, what sorts of quantum technologies might be best suited for creating memory so we can get the type of secure communication that you mentioned.

Senator BALDWIN. Thank you.

Senator HICKENLOOPER. Thank you, Senator Baldwin. Now I have questions—and for those of you who haven't been closely following the processes of the Senate, Senator Young was, I think it is fair to say, the principle moving force behind the CHIPS and Science Act and helped begin it. Would not let it go. Continued to push it various times. It got tied up. He was relentless.

STATEMENT OF HON. TODD YOUNG, U.S. SENATOR FROM INDIANA

Senator YOUNG. Well, thank you, Chairman. That is kind. And I did want to be here for this panel. I thank all of you for your work and for your presence here so that we might have an opportunity to discuss the CHIPS and Science Act, which we think can significantly further our position as it relates to American leadership in emerging technologies.

That, of course, will be vital to our national security and our economic health in the future. One of the key provisions in the CHIPS and Science Act is the regional tech hub provision. This will activate underutilized, and in some respects overlooked, regions around the country and support the innovation of critical emerging tech areas like quantum and artificial intelligence and some other key areas.

My state, Indiana, is going to benefit enormously from the establishment of these tech hubs that will bring together a wide array of stakeholders. It is really why it is so important that we not only celebrate the passage of this landmark bill, and a number are, but continue to focus on its implementation and fund key provisions such as the regional tech hub provisions.

Just ask Mr. Clark, sir, why is it important for your mind that we fully fund the CHIPS and Science Act? And how will it directly impact the work that you are doing on artificial intelligence?

Mr. CLARK. Thank you, Senator. It will impact me in two ways. One, it gives the ability to create much more ways to test and assess AI systems for both economic capabilities and safety issues. We DIY a lot of our own evals in my company and we try and make those public, but it is hard to sometimes.

If we can have more evals that are public, it unleashes more companies to build more stuff using AI and creates a huge asset. And the second way is that it can allow us to fund more ambitious infrastructure in the public sector so academics can do more impactful work.

Senator YOUNG. Thank you for that. Dr. Sutor, I know you can attest to how the private sector is putting significant resources and sweat equity into the development of quantum computing. Many Americans view quantum as it's just another pie in the sky, Silicon Valley buzz word.

It is never really going to impact their lives in a positive way. Can you discuss why in fact it is the opposite. And maybe elaborate on the many ways quantum technology is going to impact all of our lives moving forward?

Dr. SUTOR. Let me give two examples where I think many Americans, many people around the world are already using quantum. For people who have ever had a knee or a shoulder injury and have gotten an MRI, that is quantum technology. It is higher resolution and usually much safer than X-rays. That technology was developed originally in the United States going back to the 1940s.

So people haven't realized they have been doing that. But even more common is GPS. We have quantum atomic clocks in satellites right now that not only give us precision location, and just as we drive as I got here this morning, walked here this morning, but they give us highly reliable timestamps that we use in high speed networking situations.

If you go to an ATM and you see the little printout there of what time it is that comes from GPS, that comes from quantum as well. So in many ways, quantum is already part of our lives, and it will become increasingly more so.

Senator YOUNG. Those are powerful examples. And in your testimony, you note that through the CHIPS and Science Act, in the National Quantum Initiative, the Federal Government has already taken some important steps to secure our quantum future. But as you mention, there is more that needs to be done. What more can the Federal Government do, what more should we do to ensure the U.S. wins the global quantum race?

Dr. SUTOR. Well, I do believe that it comes down to talent and it comes down to skills ultimately. There has to be somebody that develops this technology. There has to be somebody to use the technology efficiently. So we have to ensure one way or another, either we can train the people we have, or we can get them.

Quantum talent is spread around the world, including with many of our allied nations. For example, the Five Eyes countries as well. So I do think we have opportunities to look beyond our borders to get the talent we need to evolve this the way we must.

Senator YOUNG. That is good. And so my constituents who might be watching this would be encouraged to know that the CHIPS and Science Act actually creates some mechanisms and can accommodate crowding in talent and treasure from our closest allies and developing things like the field of quantum. So thank you again all for being here. Chairman.

Senator HICKENLOOPER. Excellent questions. And I think that it does bear just a moment of diversion on the issue around the workforce and immigration. And I think that one of the unique advantages we have in the rivalry, the competition with China, with countries all around the globe, is that as the leader of the free world, we are recognized for the group of freedoms that we sometimes take for advantage and yet make us a very attractive destination for highly skilled scientists from all over the world.

And I think it would be interesting just to take a moment off and just ask each of you how you look at that, just I want to make sure that I get you each on the record saying, yes, we need to look at trying to attract and welcome, really welcome talent.

And by that, by welcoming, I mean they don't come just for a year or two. They get to help be part of our ecosystem on a longer term. Dr. Albritton, why don't you start.

Dr. ALBRITTON. I think we need all the talent that we can get. I think you can look at any of the universities in the U.S. and see that the talent comes from across the world, not just locally or even within the U.S.

Many of the companies we are talking about, their founders are from out of the U.S. but have found homes in the U.S. So being an open and a welcoming space, I think gives us a technological advantage that we can capitalize so that we have a brain collective in the U.S.

We not only educate our own brainpower, but we also pull it in. And we will be richer and more diverse, and I think more productive as a result.

Mr. CLARK. As a recently naturalized American citizen, I really care about this. Forty-three percent of the people at our company come from outside America. They are the best and brightest. And the thing that breaks my heart is that we put a huge amount of resources into giving them a path to stay here and sometimes it is just difficult and they have to go home. I wish that we could give a path to everyone.

Senator HICKENLOOPER. All right. Appreciate that.

Mr. BRECKENRIDGE. Yes. And being at a university, we certainly see a diverse level of students that are here. We absolutely need the smartest people. And there is quite a supply of talented individuals in the U.S. even though that we are not reaching out to. I think there is opportunities for us to improve the interest and desire to participate in STEM fields.

Senator HICKENLOOPER. Yep.

Dr. SUTOR. So I would add, in addition too, I would say the university considerations. ColdQuanta is already an international company, a 200. We have an office in the UK, in Oxford. We have terrific skills, so we get to augment what we do with the University of Colorado, the University of Chicago, the University of Wisconsin, with Oxford University as well.

So these types of international partnerships so we can achieve our goals are extremely important. So, yes, by all means, bring the talent here, but let's use the talent where it exists to get to where we need to be.

Dr. JONES. Indeed, we have no monopoly on intelligence and drive, and an inherent desire to be successful and change the world. And I think, just as you said, Senator, that is an enormous competitive advantage for us.

And how awesome is it that Mr. Clark is a fellow U.S. citizen with me to sit here and testify in this location on this topic, and he is just as wholeheartedly in favor of a strong America as those of us who were born here.

Senator HICKENLOOPER. My grandfather used to say oftentimes the adopted child is more passionate about their parents than the natural born. Mr. Lupien, do you want to——

Mr. LUPIEN. Yes. Thank you, Senator. You know, I think I share my view of my colleagues, technology has made the world a much smaller place. But I think what we need to do is not only look to bring individual talent, but by putting forward smart regulation—companies want to be in the United States. And I think we want to create a welcoming environment to not only bring individual talent, but to bring companies here as well.

Senator HICKENLOOPER. Great. Point well made. Thank you for that. All right. Now, I am going to shift back to—in case you didn't notice, we have been rotating Democrat, Republican to make sure this hearing is bipartisan as much as humanly possible.

Senator Rosen is one of the few and maybe the only Senator who has actually created software and probably understands more about technology than most of us. Senator Rosen.

STATEMENT OF HON. JACKY ROSEN, U.S. SENATOR FROM NEVADA

Senator ROSEN. Oh well, I think there is a lot of smart—thank you for that. There is a lot of smart people here. I just wrote computer code for a living, so maybe I do have a certain knowledge, but you are a scientist as well and there are other engineers and, but I appreciate that.

And of course, thank you for Chairing, and thank you for everyone for holding this important—the witnesses for being here as I am listening to you speak about what we need, the creative and talented individuals that are going to build our workforce. People to do the work of the 21st century.

We passed the CHIPS and Science Act. We have the bipartisan infrastructure law. We are going to need talented, creative people to do so many things. But today I want to talk about the talented and creative people that we are going to need to help work on artificial intelligence applications for cybersecurity, because according to Acumen Research and Consulting, the global market for security products with artificial intelligence, well it is expected to reach over $133 billion by 2030.

I talked about this today. AI technology is rapidly evolving. It is essential we dedicate research to understanding the full advantages, what AI can do and of course what it can't do, and its risk and its applications for cybersecurity. And we want to be sure all industries have access to this information and technology so they can responsibly plan—will just speak here about cyber-attacks, and especially to our AI related tools.

So, Mr. Clark, how can AI related, or AI, excuse me, enabled tools, well, they can be used to strengthen our cybersecurity posture across industries, and then on the same hand, in what ways does AI fall short as a cybersecurity solution?

Mr. CLARK. Today, AI systems have started to be able to understand code. They can write and generate code and you could use that to—in the same way I could spot a sentence that has poor grammar using a line and a language AI, I could spot code that has bugs in it using a code AI.

So we are right at the beginning of really, really exciting and useful capabilities here. However, when I wrote my oral testimony using a language AI, I checked what it wrote before I said it to the assembled Senators.

And so these kind of applications for cyber-defense are going to require people working with systems in partnership and really,

really vigorous and well-funded testing to find out if these systems can be truly relied upon.

Because in the cyber context, you absolutely don't want something to, for lack of a term, wing it. Thank you.

Senator ROSEN. Right. No, I agree. Computers are very good at either/or. It is this or not this. It is all the algorithms. It is greater than, less than—they are binary. And so I think you are right where we have to have the human component and that is going to get us to the human component built upon STEM and cyber workforce shortage.

We know we have to grow our STEM workforce, our cyber workforce across the board. We have 700,000 positions that are open across the country. I have bipartisan legislation with Senator Blackburn to invest in cybersecurity apprenticeships.

Senator Capito and I have launched the Women in STEM Caucus to bring more women into these wonderfully creative STEM jobs. Worked on a world bipartisan STEM Education Act.

Of course we know the CHIPS and Science Act. But there is just so much more to do. So, Dr. Albritton, how can the Federal Government work better with, I would say, creating maybe apprenticeship programs perhaps, certificate programs, 2 year, 4 year degrees across the spectrum?

We need all kinds of folks in this realm. How do you work better to potentiate and create this creative new workforce we are going to need and bring in girls and underrepresented communities?

Dr. ALBRITTON. Absolutely. So I think one of the things we need is long term, stable investment and building the number of educators we have and the diversity of educators that work with our students to show them the excitement.

I think investment—we can't always think about the next six term pay off, but what will pay off in 5 and 10 years. And I often think when we think about education, we are starting at an early age, maybe high school, maybe elementary school.

So I think it is having staying power and being willing to invest over time so that you can reap the rewards at some later time. And a lot of research is like that. So patience, I guess, is one of the best ways to do it and invest long term—long term, stable investment in education.

Senator ROSEN. I couldn't agree more. I think that when you excite kids in elementary school about learning about robotics or computing or science in general, even growing plants, whatever it is, they can learn about biology, geology, computers, and they learn to internalize that at a young age. Very important. Thank you, Mr. Chairman. I yield back.

Senator HICKENLOOPER. Great. And I think we have a couple of Senators coming, but since they are not here, I will just go ahead and begin with my second round, and I hope I can slip in a question or two. Mr. Breckenridge, you lead a center with high performance computing.

Obviously, understands a lot of the—understand a lot of the limitations to how we make sure that these technologies have broad and equitable access across the country. You talked about that a little bit. Several people have talked about that but you as well in your opening statement.

That—and the needs of the diverse workforce. How is access to supercomputing, as it is just now reaching more research institutions, how can we promote that equitable access and make sure that emerging technologies like quantum computing are getting the maximum benefit from all over the country in terms of how we build out the engineering that Dr. Sutor talked about?

Mr. BRECKENRIDGE. Sure. So high performance computing is becoming ubiquitous. Most research universities, maybe even all research universities, have high performance computing assets there. They may be large, they may be small, but it gives them the ability to utilize those assets.

I think we have got to do the same thing with emerging technologies, whether that is quantum or other areas that allows the faculty member, the researcher, the student to think of new and novel techniques and technologies. And without having that immediate access, it is really limiting.

Senator HICKENLOOPER. Right. Yes, I couldn't agree more. Now I will—I am not done with my second round, I am just taking a short hiatus. Senator Peters.

STATEMENT OF HON. GARY PETERS, U.S. SENATOR FROM MICHIGAN

Senator PETERS. Thank you, Chairman Hickenlooper. Thank you for taking a little hiatus for me. Mr. Clark, in your written testimony, you discuss the importance of prioritizing the development of resources for testing, evaluation, and benchmarking of artificial intelligence systems.

In Michigan, we are the home of the auto industry and have been investing significant resources into AI systems to pilot autonomous vehicles that will be able to drive through complex city environments without a human driver. But the secret to all of that is AI systems that are able to pilot these automobiles and handle the massive amount of data coming in from all of the sensors.

Now, it has been described to me that self-driving cars is basically the moonshot for AI. When AI was able to do that, AI has really proven itself to be able to do all sorts of things that will transform industry in meaningful ways. So I would like you to discuss some of the existing barriers to testing, evaluating, and benchmarking of AI, and what resources do you think we will need to overcome these obstacles?

Mr. CLARK. Thank you, Senator. This is a matter close to my personal interest. An area that is crucial to doing self-driving cars well is very large-scale high fidelity simulators.

You need to simulate not just the cities that you are trying to drive your cars around, but you also need to simulate people in the cities, weather conditions, all kinds of variation and that takes resources, and specifically it takes computational power.

So for more of what we can give researchers access to large amounts of computation to run high fidelity simulations, the better we can train these vehicles. That is a fundamental block.

Senator PETERS. Well, thank you. And another question for you, Mr. Clark. While we know that AI can deliver some substantial benefits to society, I am also concerned that AI will create some significant new dynamics when it comes to cybersecurity.

Providing certainly increased speed and agility for both our network defenders, but unfortunately also for our adversaries when it comes to cybersecurity. So how should we be thinking ahead about ways to continue to improve cybersecurity as advances in AI continue to march forward?

Mr. CLARK. We can take AI systems and pair them with human experts who will kind of teach the AI systems about how to secure cyber infrastructure. And you can think of it as like creating a digital immune system for our networks.

AI model that constantly watches networks and watches for suspicious activity and tries to actively heal them and repair them. Additionally, we do need to invest in analysis of what is going on abroad. Other groups are harnessing this stuff for not just defense, but offensive purposes.

And if we don't have a very clear and calibrated sense of where those capabilities are, we could get surprised, which is not what any of us want.

Senator PETERS. No, absolutely not. We need to lean forward aggressively in that area. I appreciate that answer.

Dr. Sutor, in May, the Biden Administration issued a national security memorandum requiring more proactive engagement with critical infrastructure owners and operators to ease the migration of our computer systems from today's standard encryption algorithms to quantum resistance cryptography.

So my question to you is, what do you see as the key challenges for the private sector in this migration?

Dr. SUTOR. I think even if we don't mention the word quantum, it can take up to 10 years, for example, for a bank to move to a new cryptographic protocol. It is a lot of work. It touches many different parts of their systems. So even if quantum computers today cannot break encryption, if they can do it in 10 or 15 or 20 years, it is a significant problem.

And so it is something that people have to look at and do a real evaluation. What sort of cryptographic profiles, techniques do they use today? Are they RSA? Are they elliptic curve, for example? When might those be broken and what should they put in place to be safe about that?

I might also add there are export control issues concerning this, which is, where do we think quantum computers might be able to break crypto? And what should we do about that with respect to export controls?

There has been some very solid work there to define the sweet spot to maintain competition developments of the technologies while still protect national security.

Senator PETERS. Right. Thank you. Thank you, Chairman Hickenlooper.

Senator HICKENLOOPER. Great. I am going to—I have been told that they are holding a vote open for me on the Senate floor. I am the last person to vote. So I am going to ask one last question of Dr. Albritton, and I am not going to get to come hang out, which is usually my favorite part.

Once we have gotten all this out on the table, then chew it over for another 10 or 15 minutes. As you try to leave, I would normally restrain you. At least do my best. Dr. Albritton, we talked about fairness a little bit with AI, trustworthiness, I think, is another issue that we keep hearing about more and more.

The trustworthy AI systems are more fair, more transparent, more explainable, more robust, I think in many cases. As requirements for AI systems become stricter, what advantages could American companies see if they continue—if we continue to make sure we lead the world in making AI trustworthy?

Dr. ALBRITTON. I think the advantages are unbounded. I mean, you could go and be confident that no matter what your race or sex, you will—the facial recognition programs will treat you equivalent to everybody else. When you apply for a job, you will get the best candidate.

You will not have a biased AI program, maybe selecting for certain attributes. So I think it is a more equitable, a more diverse, and a more economically productive world, if we can do that, because we will have everyone playing on a level playing field and everyone will have a chance.

It is a world now, we have heard about all the great competition. We have got to have everyone having a chance, no matter what your background, what your other demographics are, your economics, et cetera. And I think a fair, more fair AI will give us all those things we need.

So economically, the U.S. is far, far better off with fairer systems, in my mind.

Senator HICKENLOOPER. Well, I couldn't agree more. And I think you have all in different ways played a role in creating that, the constantly improving sense of fairness and trustworthiness.

Thank you each, Dr. Albritton, Mr. Clark, Mr. Breckenridge, Dr. Sutor, Dr. Jones, Mr. Lupien. I think I have questions for each of you that will go into the written—put them in writing to you. I guess this will then end today. You are off the hook now. Conclude our hearing for today.

I would like to thank all my Senate colleagues and especially our witnesses for this, I think truly fascinating discussion. I think the best hearings are the ones where you come away from it and you have got more thoughts in your head than you came in with, and I think that is certainly true to, maximum effect today.

The hearing record will remain open for questions for two weeks until October 13, 2022. Any Senator who would like to submit questions for the record may do so. Until then, we ask that witnesses submit their responses to those questions by October 27, 2022.

There will be harsh penalties—no, I am just kidding. With that, this committee is adjourned.

[Whereupon, at 12:05 p.m., the hearing was adjourned.]

A P P E N D I X

Response to Written Questions Submitted by Hon. Maria Cantwell to Dr. Nancy Albritton

Compute Access: Academic institutions represented the majority of large-scale AI experiments from the 1960s until 2010. U.S. News and World Report (2022) ranks the University of Washington (UW) as one of the Top 5 Artificial Intelligence Programs[1] in the Nation. In July 2021, UW won a $20 million dollar grant over 5 years from the National Science Foundation (NSF) to establish a new artificial-intelligence research institute for dynamic systems. However, over the past decade the industry-academic balance has altered, with the vast majority of large-scale AI research carried out by industry. Building large-scale AI models can cost tens of millions of dollars and require 300,000x more computing power than experiments conducted in the prior decade.

Question 1. What are the specific gaps you are seeing in the availability of AI computing resources in industry, government, and academia? Besides the National AI Research Resource, what else can the U.S. government do help academia remain competitive, or better collaborate with, private industry in AI research development?

Answer. Thank you for your leadership of and investment in science, technology, engineering and mathematics through the development and passage of the CHIPS and Science Act. Artificial intelligence and machine learning have spurred significant scientific breakthroughs in healthcare, biology, and materials discovery. For example, DeepMind's solving of decades-long challenge of protein folding; the use of machine learning for more effective chemical synthesis; and PostEra's accelerated development of COVID-related drug discovery. More resources invested in emerging technologies will generate sizable social and economic benefits.

At the same time, we need more investment in AI policy and national strategies to address ethical concerns (equity, fairness, etc.) associated with using AI/ML. There are very limited efforts to address these concerns in the industry. Emerging connections between AI and quantum computing are advancing rapidly. For example, quantum computing provides training sets for AI, which then learns how the quantum world behaves and can make predictions without solving the exact quantum problem each time. Increased Federal investment in quantum computing will be critical to maintain our global competitiveness. To continue to accelerate discovery sustained and increased funding of the Federal agencies that enable us to remain a quantum information leader in a fierce global landscape is required.

AI Skills Gap: In a recent survey in the United States and United Kingdom, 93 percent of surveyed companies reported AI as a strategic business priority; however, 51 percent found that they lack the right mix of skills to fully realize those strategies.[2] As the Frank & Julie Jungers Dean of Engineering, you serve as the Chief Academic Officer of the College, overseeing $159 million in research expenditures and providing leaderships to over 279 faculty and more then 8,000 students.

Question 2. How do you recommend the U.S. narrow this AI-skills gap in industry and, specifically, what can educational institutions like UW do build a robust and inclusive pipeline of students to meet the growing demand?

Answer. Universities can play an important role in narrowing the AI-skills gap in industry. At the UW we are in the midst of diversifying our curriculum to ensure that all students have foundational skills in AI and machine learning. For example, in the EU, the vast majority of specialized AI academic offerings are taught at the master's level; robotics and automation are by far the most frequently taught course in the specialized bachelor's and master's programs, while machine learning (ML) dominates in the specialized short courses.

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[1] *https://www.usnews.com/best-graduate-schools/top-science-schools/artificial-intelligence-rankings*

[2] *https://www.snaplogic.com/company/media/press-releases/ai-skills-shortage-research*

In addition, we must advance programs to promote diversity in AI. Currently, female graduates of AI PhD programs in North America have accounted for less than 18 percent of all PhD graduates on average, according to an annual survey from the Computing Research Association (CRA). The CRA survey shows that in 2019, among new U.S. resident AI PhD graduates, 45 percent were white, while 22.4 percent were Asian, 3.2 percent were Hispanic, and 2.4 percent were African American.

Failing to prepare our citizens for the innovation economy compromises our Nation's long-term competitiveness and economic stability and disadvantages our citizens and communities. Industry, government and universities must step up and invest in the STEM workforce. As we enter an increasingly specialized economy, America's leading research universities, including the University of Washington, are uniquely poised to provide leadership, research, and workforce education to meet this need, but we need Federal investment to support these endeavors.

STEM Training: You mentioned in your testimony that there is fierce competition to hire STEM faculty to educate students. You also mentioned that the University of Washington has turned away excellent students because student demand exceeds the capacity of your STEM programs. The CHIPS and Science Act authorized $13 billion for STEM education to help close the gaps in training the STEM workforce.

Question 3. What types and levels of Federal funding do you think might be most effective at helping close the STEM training gap? As possible, please provide information on the roles of different types of funding (*e.g.,* scholarships, research funding, infrastructure support, and teacher professional development and hiring support) and on suggested funding agencies, as well as information on how many additional students could result from each.

Answer. Investment in the Nation's STEM educational system is essential to grow our economy while preparing our students for the fields of tomorrow. STEM graduates drive innovation in health, clean energy, technology, aerospace and infrastructure, but our state's industries turn elsewhere for workers because our universities cannot keep up with demand due to the lack of faculty, space and resources. Insufficient STEM capacity denies our state's students access to high-impact career opportunities. This inaccessibility is particularly acute for students traditionally underrepresented in these fields.

To address the STEM training gap effectively, we need the government at the Federal and state level, industry and academia all working together. Continued investment in our Federal agencies such as NIH, NSF, DOE, is critical to these efforts as well as funding for key programs like Pell Grants. In the last academic year close to 11,000 UW undergraduates received Pell Grants, more than all the Ivy Leagues schools combined. The UW awards $100 million a year in institutional grants and scholarships to Washington students to help them pursue their education. A third of our undergraduates are the first in their families to attend college. We receive more Federal research dollars than any other public university in the Nation. Research funding pays for graduate trainees as well as undergraduate research experiences. More than 7,000 undergraduates conduct research per year at the University of Washington. Core facilities and instrumentation dedicated to training and research is often very expensive and shared resources will enable access for all to state of the art equipment both in academia and industry. Finally, STEM engagement, education and experiences at all high and middle school levels is foundational to our future success.

Thank you for the opportunity to participate in this important hearing.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KYRSTEN SINEMA TO DR. NANCY ALBRITTON

Drought and Fire Monitoring at NOAA: Fire season began in late April in Arizona, as the Southwest experiences the most severe drought in twelve hundred years. The Tunnel Fire north of Flagstaff burned over twenty thousand acres while the Crooks Fire consumed over six thousand acres south of Prescott. After the fires were extinguished, burn scars have led to significant flooding issues in Flagstaff and other areas in northern Arizona.

Arizonans rely on National Weather Service predictions and National Oceanic and Atmospheric Administration (NOAA) data to predict fire trajectory and to determine impacts to landscapes and human health. It is important that NOAA and the Weather Service have the resources and expertise needed to predict weather and drought conditions.

Earlier this year, NOAA launched two new supercomputers, including the "Cactus" supercomputer in Phoenix, Arizona, which operates at a speed of 12.1 petaflops.

Question 1. The bipartisan infrastructure law included $80 million dollars for NOAA high-performance computing technology and $50 million for wildfire prediction, detection, and forecasting. How will these resources allow NOAA to improve drought and wildfire prediction forecasting?

Answer. A record number of our citizens experienced extreme weather in this past year. These significant Federal investments will enable NOAA to procure research-supercomputing equipment used for weather and climate model development to improve drought, flood, and wildfire prediction, detection, and forecasting. The high performing supercomputing infrastructure is necessary for the long-term benefits of revealing the underlying correlation between climate change, environmental impact and natural disasters, hence contributing to our ability to understand the complex and large-scale ecosystem.

NOAA plays a critical role supporting federal, state, local and tribal partners in preparing for the threat of wildfires and in battling the blazes that endanger life and property. NOAA's forecast products range from short-term warnings to long-term seasonal predictions, and include air quality and smoke forecasts related to wildfires. NOAA also provides real-time fire and smoke detection tools using new imaging capabilities from geostationary and polar orbiting satellites. The recently launched JPS–2 satellite will support essential forecasts for extreme weather events, feed daily weather models, and monitor climate change. Weather forecasters, first responders, pilots, climate scientists and fire crews will use the data collected by the satellites.

STEM Education in CHIPS and Science Act: The bipartisan CHIPS and Science Act authorized $13 billion over five years for the National Science Foundation (NSF) to put towards Science, Technology, Engineering, and Mathematics (STEM) education. The legislation directs the NSF to explore opportunities to engage students from groups historically underrepresented in STEM fields as well as rural areas to expand the pipeline to help ensure the United States has the STEM workforce we need for the Twenty-First Century.

Question 2. How will the CHIPS and Science legislation expand STEM education and, in turn, America's STEM workforce? Why is it important for Congress to fund the investments in STEM education made in the legislation?

Answer. Investment in our Nation's STEM educational system is essential to maintain and grow our economy. STEM graduates drive innovation in health, clean energy, technology, aerospace and infrastructure, but our states' industries often turn elsewhere for workers because our universities cannot keep up with demand due to the lack of faculty, space and resources. Insufficient STEM capacity denies our citizens access to high-impact and high-earning careers. This inaccessibility is particularly acute for individuals traditionally underrepresented in these fields.

A thriving economy demands a well-rounded workforce for long-term competitiveness. Failing to prepare our citizens for the work of the future compromises our country's long-term competitiveness, security and economic stability. To remain competitive on a global stage we must increase the STEM pipeline, its diversity and leverage all of our talent.

Investment in America's leading research universities through the CHIPS and Science Act will allow talented faculty and students to further innovative science that will elevate the U.S. as a global destination for knowledge and discovery in quantum information sciences. These foundational investments will influence economic and national security, prepare U.S. students for jobs with quantum information technology, enhance STEM education at all levels, and accelerate exploration of quantum information frontiers, all while expanding and diversifying the talent pool for the industries of the future across the Nation.

Semiconductor Investments: Once the global leader, America now only accounts for approximately 12 percent of the world's semiconductor manufacturing. Recognizing this important national security issue, I worked with my colleagues to ensure the CHIPS and Science Act also appropriated $52 billion for the Commerce Department to establish grants to jump-start investments in America's domestic semiconductor industry. These investments will support tens of thousands of Arizona jobs at facilities managed by Intel, TSMC, and other Arizona semiconductor companies.

Question 3. How does the CHIPS and Science Act and the law's semiconductor investments illustrate the United States' commitment to being a global leader in this field and what further actions can be done to expand U.S. leadership in this field?

Answer. Recognizing that the U.S. semiconductor industry's dependence on offshore manufacturing poses a threat to the Nation's long-term economic competitiveness and national security, the passage of the CHIPS and Science Act was critical to the development of new programs to promote research, development and fabrication of semiconductors within the U.S.

In the past decades, Institutes of Higher Education in the U.S. have lost footing in semiconductor design, engineering and manufacturing curricula. This is because the majority of semiconductor manufacturing has been produced outside of the U.S. and because industry has been leading the field both in personnel as well as in technology.

The technologies and processes required to design and manufacture semiconductor chips continue to become more sophisticated, requiring a workforce with a wider and more flexible range of STEM skills. Today significant gaps exist between the industry-oriented skills in demand and the traditional skills being supplied. A 2017 survey conducted by Deloitte and SEMI [3] found that 82 percent of semiconductor industry executives reported a shortage of qualified job candidates, and the challenges of finding qualified workers have increased since then, with gaps at all skill and education levels—from technicians to doctoral-level engineers. The workforce needs of the industry are expected to more than double as the CHIPS Act manufacturing incentives in the U.S. will create tens of thousands of new jobs within the next few years, concentrated in technical and engineering roles.

The CHIPS and Science Act is a significant investment in new programs to promote the research, development, and fabrication of semiconductors within the U.S. I ask that you continue to accelerate discovery through sustained and increased funding of the Federal agencies that enable us to remain a STEM leader on a fierce global landscape. Specifically, continued and additional investment to secure U.S. leadership in microelectronics manufacturing is needed. In addition, the establishment of a national network for microelectronics education that is open to all U.S. universities and colleges to participate in and that industry and government stakeholders can collaborate.

[1] *https://www2.deloitte.com/us/en/insights/industry/technology/growing-semiconductor-market.html*

[2] *precedenceresearch.com/semiconductor-market*

[3] *https://www.semi.org/en/workforce-development/diversity-programs/deloitte-study*

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. RAPHAEL WARNOCK TO DR. NANCY ALBRITTON

Workforce Diversity:

Question 1. What is the importance of fostering greater diversity within America's science, technology, engineering, and mathematics (STEM) workforce, and to what extent would failure to diversify our workforce hinder our national and economic security?

Answer. Studies have shown that diversity fosters greater outcomes in problem solving than monoculture groups. Diversity increases problem solving skills, creativity and conflict resolution. Black and Hispanic workers continue to be underrepresented in the STEM workforce, while White and Asian workers are overrepresented. STEM degrees lead to high-impact career opportunities, which can lift up communities.

Investment in our Nation's STEM education system is essential to maintain and grow our economy. STEM graduates drive innovation in health, clean energy, technology, aerospace and infrastructure, but our states' industries often turn elsewhere for workers because our universities cannot keep up with demand due to the lack of faculty, space and resources. Insufficient STEM capacity denies our citizens access to high-impact and high-earning careers. This inaccessibility is particularly acute for individuals traditionally underrepresented in these fields.

A thriving economy demands a well-rounded workforce for long-term competitiveness. Failing to prepare our citizens for the work of the future compromises our country's long-term competitiveness, security and economic stability. To remain competitive on a global stage we must increase the diversity in STEM and leverage all of our talent.

Question 2. What role do historically black colleges and universities (HBCUs) and other minority-serving institutions play in helping to build a diverse workforce? What lessons can universities and other institutions draw from the success of HBCUs in supporting our STEM workforce?

Answer. HBCUs play an important role in building a more diverse workforce. A quarter of Black STEM graduates come from HBCUs. Forty-six percent of Black women who earned STEM degrees between 1995–2004 graduated from HBCUs. The institutions of origin for 30 percent of Black graduates earning doctorates in science and engineering were HBCUs.

There is a greater need for equity throughout our educational system and in industry hiring. HBCUs serve students who are first-generation, low-income, and welcome people from any race to attend. Universities across the Nation would be well served by mirroring this inclusive approach and support diverse STEM students, staff and faculty throughout their educational and professional journeys. There are numerous opportunities for government, industry and academia to come together to create STEM career pathways for all of our citizens.

Rural Institutions: Georgia is a proud agricultural state, and I am particularly excited for how advanced technologies will help improve precision agriculture and otherwise support America's farmers. I am concerned, however, by the underrepresentation of rural students and rural colleges and universities among America's leading research institutions and the effect this will have in fields such as precision agriculture.

Question 3. What barriers do rural students face in entering the workforce in advanced technologies such as artificial intelligence and quantum computing? How can Congress help address these barriers?

Answer. Rural students face numerous barriers in accessing education that would allow them to pursue careers in advanced technologies. Rural schools are often disadvantaged by the way education funds are calculated and distributed as smaller enrollments result in fewer dollars. In addition, child poverty levels in rural areas can be double that of urban communities. Rural residents attend college at a lower rate than urban residents (19 percent to 35 percent).

The lack of financial support from the community and lack of visibility with private funders challenges rural schools. Urban schools often receive priority with grants and research to improve their conditions while rural schools garner less attention. Teacher pay is often much lower in rural areas than in urban areas and that impacts recruitment and retention of new and qualified teachers. Rural parental and community opinions of STEM education are often incongruent with the need for students to learn certain skills and principles of the field to be competitive.

Some problems exist for rural schools to take advantage of supplemental government grants and funding, so Congress should be mindful of these potential pitfalls. For example, the Rural Education Achievement Program (REAP) designed to assist rural schools with administrative challenges in their school systems. Stipulations on fund use sometimes create unintended burdens (*e.g.,* requiring that a percentage of the award be set aside for supplemental educational services, but this is a costly hardship for remotely located schools).

Question 4. What barriers do rural colleges and universities and their faculties face in accessing and supporting research related advanced technologies such as artificial intelligence and quantum computing? How can Congress help address these barriers?

Global Collaboration and Competition: I have long believed that America must invest in innovation and advanced technologies to maintain our global standing. I am deeply alarmed that our global competitors, such as the Chinese Communist Party, have heavily invested in technology research and used it to oppress its own people and bolster autocratic regimes throughout the world. To keep America on the leading edge, Congress must strike the appropriate level of controls on innovation and intellectual property to protect our national and economic security without overly hindering scientific innovation and international collaboration.

Answer. In a competitive global market, there is great demand for qualified individuals in STEM fields. Rural schools struggle to prepare people to compete at an early age in STEM fields. To maintain our economic and intellectual global leadership we must offer equal STEM educational opportunities to all students. Rural communities lack access to resources for STEM education, incongruent local values between local culture and economic demand, rural poverty, and gaps in outreach to rural communities for aid and research.

Jobs in AI are well suited for remote work in rural areas if tools are accessible. AI could help address problems in rural communities such as the opioid crisis and crop production in farming and agriculture. STEM education is the foundation for lucrative careers in AI and data science. Expanding digital connectivity and investing in workforce development and government, academia and industry partnerships could transform local economies and reduce disparities in earning capacities.

References: Maskey, S. (2021, April 13). *We need to teach AI in rural America.* Forbes. *https://www.forbes.com/sites/forbestechcouncil/2021/04/13/we-need-to-teach-ai-in-rural-america/?sh=2352852e418b*

Harris, R.S. and Hodges, C.B. (2018). STEM education in rural schools: Implications of untapped potential. *National Youth-At-Risk Journal, 3(1). https://files.eric.ed.gov/fulltext/EJ1269639.pdf*

Question 5. What are the key concerns that Congress should keep in mind as we work to achieve this balance? Please share any examples of Federal programs that you believe do not strike the right balance.

Answer. Rural America is facing a maelstrom of disparities, exacerbated by the widening technology divide. Many rural areas lack reliable cost-effective energy resources. Deficient digital connectivity in rural areas has led to poor health and economic under-development. We must re-think digital innovation as a process to reconnect and remap the economies in rural and urban areas. Institutions of higher education are uniquely positioned to take advantage of the powerful tools developed in the digital industry and lead a new type of digital ecosystem due to their strengths in fostering entrepreneurship, workforce education, collaboration with the private sectors and national laboratories, promoting diversity and inclusion and being a natural nexus to technology and society.

I urge you to continue to invest in our Federal science agencies and initiatives empowered by CHIPS. Sustained Federal investment in these programs are essential for our Nation to remain a leader in a fierce global landscape, to leverage opportunities for collaboration between government, academic, and business sectors, and to build a workforce that reflects the rich diversity of our Nation.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARIA CANTWELL TO WILLIAM B. (TREY) BRECKENRIDGE III

Supercomputing Leadership: You noted in your testimony that the United States is losing its lead in high-performance computing to China. In 2015, the United States had nearly twice as many of the Top 500 supercomputers as China. Today, however, China leads with 173 supercomputers, compared to 123 in the United States. The U.S. Department of Energy (DOE) owns four of the top ten fastest supercomputers in the world according to the June 2022 Top500 list. The Frontier supercomputer at the DOE's Oak Ridge National Laboratory (ORNL) is ranked as the fastest computer in the world.[3]

Question 1. Given that other computational capabilities are readily available to a broad group of industry, academic, and Government entities, what importance should policymakers assign to ensuring that the United States has access to the world's fastest supercomputers? Are there specific examples where the United States lacking these capabilities has led—or will lead—to a strategic disadvantage?

Answer. Supercomputing access is the future of R&D in all STEM fields. The development of new technologies and modeling capabilities simply cannot happen without high performance computing capability. While access to supercomputing resources has significantly increased over the last decade or so, there is not adequate capacity in those systems to meet the needs of those communities utilizing them. As was the case when we began improving Internet connectivity, those who are limited in high performance computing capacity simply will be left behind globally to those who have the robust, high-speed tools for data analytics, modeling capacity, and research throughput.

However, simply increasing HPC capacity is not sufficient to ensure high-end computing needs are met. While the number of systems on the TOP500 list is an indicator of availability of access to HPC, it is not an indicator of overall capability. For instance, the Frontier system at Oak Ridge National Laboratory has more computing capacity than the remaining 127 U.S. systems of the TOP500 list added together. To address the massive, highly complex workloads of grand challenge problems, such as quantum mechanics, climate change, and security, and to remain competitive globally in these critical areas, the U.S. must fund more capability-class HPC systems—systems with significantly higher performance than the lower 90 percent of the TOP500—and make these systems available to U.S. scientists and researchers.

Compute Access: Academic institutions represented the majority of large-scale AI experiments from the 1960s until 2010. However, over the past decade the industry-academic balance has altered, with the vast majority of large-scale AI research being carried out by industry rather than academia. Private industry is leading in AI development, because they have the large-scale resources, and therefore the access, to carry out frontier AI research. Building large-scale AI models can cost tens of millions of dollars and require 300,000x more computing power than experiments conducted in the prior decade.

Question 2. What are the specific gaps you are seeing in the availability of AI computing resources in industry, government, and academia, and to what extent do gaps differ in the regulated (*e.g.,* classified) and unregulated spaces? Besides the National AI Research Resource, what else can the U.S. government do to catch up to private industry, or better collaborate with private industry, in AI development?

Answer. Industry has indeed made major investments in R&D related to AI technologies. Funding programs should be designed that encourage more government-industry-academic partnerships. Rather than viewing them as competitors, collaboration will be critical if we are to move forward as a Nation in leading AI technology development and application.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KYRSTEN SINEMA TO WILLIAM B. (TREY) BRECKENRIDGE III

Drought and Fire Monitoring at NOAA: Fire season began in late April in Arizona, as the Southwest experiences the most severe drought in twelve hundred years. The Tunnel Fire north of Flagstaff burned over twenty thousand acres while the Crooks Fire consumed over six thousand acres south of Prescott. After the fires were extinguished, burn scars have led to significant flooding issues in Flagstaff and other areas in northern Arizona.

Arizonans rely on National Weather Service predictions and National Oceanic and Atmospheric Administration (NOAA) data to predict fire trajectory and to determine impacts to landscapes and human health. It is important that NOAA and the Weather Service have the resources and expertise needed to predict weather and drought conditions.

Earlier this year, NOAA launched two new supercomputers, including the "Cactus" supercomputer in Phoenix, Arizona, which operates at a speed of 12.1 petaflops.

Question 1. The bipartisan infrastructure law included $80 million dollars for NOAA high-performance computing technology and $50 million for wildfire prediction, detection, and forecasting. How will these resources allow NOAA to improve drought and wildfire prediction forecasting?

Answer. High performance computing is critical to improve wildfire and drought forecasting. As modeling capabilities improve, the need for computational speed goes up exponentially. Our capacity to generate data to improve models and the accuracy thereof can be greatly limited if research does not have the computational capacity to develop and adequately use the data generated. In the same way, operational models require near real-time processing if predictions are to be relevant.

STEM Education in CHIPS and Science Act: The bipartisan CHIPS and Science Act authorized $13 billion over five years for the National Science Foundation (NSF) to put towards Science, Technology, Engineering, and Mathematics (STEM) education. The legislation directs the NSF to explore opportunities to engage students from groups historically underrepresented in STEM fields as well as rural areas to expand the pipeline to help ensure the United States has the STEM workforce we need for the Twenty-First Century.

Question 2. How will the CHIPS and Science legislation expand STEM education and, in turn, America's STEM workforce? Why is it important for Congress to fund the investments in STEM education made in the legislation?

Answer. The CHIPS and Science legislation provides an opportunity for substantial increase in NSF funding at critical juncture. Other countries have made major advances in STEM areas, and if the U.S. is to regain its leadership role investments like this are crucial. Importantly, funds are set aside in this legislation to ensure that more institutions in more states are able to participate. This will allow many, many more students to work in NSF-funded projects, broadening participation and recognizing that workforce development in STEM fields is critical throughout the Nation, and not just in a few states.

Semiconductor Investments: Once the global leader, America now only accounts for approximately 12 percent of the world's semiconductor manufacturing. Recognizing this important national security issue, I worked with my colleagues to ensure the CHIPS and Science Act also appropriated $52 billion for the Commerce Department to establish grants to jump-start investments in America's domestic semiconductor industry. These investments will support tens of thousands of Arizona jobs at facilities managed by Intel, TSMC, and other Arizona semiconductor companies.

Question 3. How does the CHIPS and Science Act and the law's semiconductor investments illustrate the United States' commitment to being a global leader in this field and what further actions can be done to expand U.S. leadership in this field?

Answer. The funding commitments that the CHIPS and Science legislation makes is a bold statement globally about the U.S. commitment to leadership in STEM fields. In addition, the funding recognizes the critical national security needs in onshore chip manufacturing. Investments in research and ensuring the environment for onshore manufacturing for the development of new technologies will be critical to ensure that the U.S. adequately addresses these national security needs. In particular, additional actions should be taken to ensure companies have access to capital for the manufacturing investments necessary as well as a trained workforce capable of meeting the demands from this added manufacturing capacity.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. RAPHAEL WARNOCK TO WILLIAM B. (TREY) BRECKENRIDGE III

Workforce Diversity:

Question 1. What is the importance of fostering greater diversity within America's science, technology, engineering, and mathematics (STEM) workforce, and to what extent would failure to diversify our workforce hinder our national and economic security?

Answer. Our Nation is founded on the principle of freedom and opportunity for all. We cannot afford to see a lack of diversity in STEM fields if we are to achieve our potential. We as a country cannot be successful if we in fact leave a segment of our population behind in technology development.

Question 2. What role do historically black colleges and universities (HBCUs) and other minority-serving institutions play in helping to build a diverse workforce? What lessons can universities and other institutions draw from the success of HBCUs in supporting our STEM workforce?

Answer. HBCUs and MSIs have historically played a vital role in ensuring higher education opportunities for all citizens of the US. As STEM fields evolve, collaboration between all institutions will be even more important than in the past. HBCUs and MSIs, in particular partnering with other research universities, will have exceptional opportunities to ensure that research funding and workforce development is broad across all demographics within the U.S.

Rural Institutions: Georgia is a proud agricultural state, and I am particularly excited for how advanced technologies will help improve precision agriculture and otherwise support America's farmers. I am concerned, however, by the underrepresentation of rural students and rural colleges and universities among America's leading research institutions and the effect this will have in fields such as precision agriculture.

Question 3. What barriers do rural students face in entering the workforce in advanced technologies such as artificial intelligence and quantum computing? How can Congress help address these barriers?

Answer. So much of the research funding in recent years has gone to a few institutions in a few states, thereby limiting access to undergraduate and graduate research opportunities across the Nation. The CHIPS and Science legislation has provided important safeguards to ensure that funding is provided more broadly to rural and underrepresented populations. This legislation ensures that quality will not be lessened, but many more students will have access to these resources so that we as a Nation can grow across the entire country.

Question 4. What barriers do rural colleges and universities and their faculties face in accessing and supporting research related advanced technologies such as artificial intelligence and quantum computing? How can Congress help address these barriers?

Answer. Access to funding has been difficult for a variety of reasons, including perceptions of quality, lack of research infrastructure, lack of state investment, and higher demands on faculty at institutions with less funding. In particular, a need exists to invest more resources in equipment and research infrastructure if rural colleges and universities are to be successful in R&D activities.

Global Collaboration and Competition: I have long believed that America must invest in innovation and advanced technologies to maintain our global standing. I am deeply alarmed that our global competitors, such as the Chinese Communist Party, have heavily invested in technology research and used it to oppress its own people and bolster autocratic regimes throughout the world. To keep America on the leading edge, Congress must strike the appropriate level of controls on innovation and intellectual property to protect our national and economic security without overly hindering scientific innovation and international collaboration.

Question 5. What are the key concerns that Congress should keep in mind as we work to achieve this balance? Please share any examples of Federal programs that you believe do not strike the right balance.

Answer. Investments in research within the U.S. is a critical step, and Congress is to be applauded for the CHIPS and Science legislation that will be a major step forward in ensuring national competitiveness. I believe Congress has done a very good job in striking the right balance between controlling and stimulating innovation. While recent policies restricting access to R&D to foreign entities have been difficult to implement, I recognize the critical need for these steps. However, funding to cover the added costs of these controls and restrictions are born by individual universities, and additional Federal funds are critically needed if rural universities are to remain competitive.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARIA CANTWELL TO DR. BOB SUTOR

QIS Technical Challenges: CHIPS and Science has authorized National Institute of Standards and Technology funding for research and development of quantum cryptography and post-quantum classical cryptography standards, as well as quantum networking, communications, and sensing technologies. By studying these fields, we can understand the impacts of quantum information sciences on cybersecurity, secure communications, and medical devices.

Question 1. What are the main technical challenges facing the quantum information science field, and how can the United States Government help meet those challenges?

Answer. The primary challenge for quantum computing systems is building large and powerful enough systems. We often measure "large enough" in terms of the number of qubits, but this is not a good metric. Having many error-prone qubits is not necessarily better than having fewer qubits with higher fidelity. The quantum programming model requires that qubits be connected to create entanglement. We will likely need hundreds of thousands of qubits arranged in arrays of interconnected quantum cores that can operate at very low error rates for application to the promised use cases in AI, optimization, and simulation of physical systems. We need breakthroughs in physics, engineering, and manufacturing to get there.

Another challenge facing quantum computing is that its programming is not a simple variation or extension of how we code software for classical applications. The model is entirely different and requires new training materials and courses. In my book, Dancing with Python, I show how this integrated approach can teach students, even at the high school level, to start understanding and coding quantum algorithms. We need national STEM programs to make quantum software development pervasive throughout our computer science curricula.

We can also make physics education more accessible via the cloud. Quantum sensors work by detecting subtle effects and variations in atomic configurations. This allows us to determine changes in speed, rotation in three dimensions, and gravity. With this technology, we can also build high-resolution atomic clocks and Radio Frequency receivers for consumer, military, and intelligence use. We need to train more students at the university level to move from the theoretical aspects of quantum computing to applied quantum engineering. Quantum matter machines, such as the quantum emulator named Albert from ColdQuanta, can give students a hands-on cloud-based interactive platform for experimenting with the physical processes at the core of quantum sensors. Just as quantum computing was jump-started in 2016 when the first system was put on the cloud, we can do the same to accelerate skills development for quantum sensors and other devices.

A major issue facing America's quantum industry is supply chain. Many essential enabling technologies for quantum technology are available only from a handful of vendors, many of which are overseas. For example, ColdQuanta's cold atom approach to quantum computing uses many different laser systems to trap, cool, and manipulate atoms. These are very specialized lasers, with only a few vendors offering systems with the necessary requirements. Sometimes we have to build our own laser systems in-house to meet our needs. Another key enabling technology that will allow quantum technology to become much more compact is Photonic Integrated Circuits or PICs. This technology is to light what microchips are to electronics; with a PIC, you can build an entire photonic system on a chip.

We must support a robust domestic supply chain. We cannot afford to allow quantum and quantum-enabling manufacturing to go overseas. To avoid that, we need to invest now in small, domestic manufacturers, building that supply chain and providing high-paying jobs for Americans.

Overcoming Valley of Death: You mentioned in your testimony that the U.S. Government's investment in quantum startups is scattered, without support for integration into deployed systems of record. The CHIPS and Science Act specifically aimed to help accelerate startup development, including through entrepreneurial fellowships, testbeds, and demonstration projects within the National Science Foundation Technology and Innovation Partnerships directorate.

Question 2. What specific policy recommendations do you have to improve U.S. investment in startups to help them cross the "valley of death"? From your perspective, do quantum and AI technologies face unique challenges, such as greater capital investment that ought to be addressed?

Answer. The "valley of death" concerning quantum startups and manufacturers is the gap between prototyping/low-volume production and high-volume production. Hardware typically requires greater and longer-term investment than software because of the prototype, development, and product cycle, together with supply chain fulfillment issues and delays. In addition, it will be several years, perhaps five to ten, until we have powerful enough quantum computers for our intended applications. The venture capital and general investment community may not have the patience to wait that long for their ROI.

Statistically, 90 percent of all startup companies in the U.S. fail. It is essential that promising small and medium-sized companies within the quantum ecosystem be supported until they can reach manufacturing scale and profitability for this technology that will be so important for our country's economic success and security.

Some of this support can come in the form described in our response to your Question 3: departments and agencies should not penalize contractors for accepting cost and schedule risk for the inclusion of highly promising quantum solutions, given the strategic importance to the Nation of accelerating the development and maturation of this high-payoff technology.

It is also critical that any legislation maintains quantum technology neutrality. At this exciting stage of technological development, there is a diversity of quantum modalities. To make quantum systems, people use atoms, ions, superconducting systems, nitrogen vacancies, photons, and more. While we at ColdQuanta believe that the neutral atom approach is the surest bet, we, as an industry, are still determining which modality will deliver the first fully functional and error-corrected quantum computer. In the case of quantum computing, if we need hundreds of thousands of qubits for practical quantum advantage, we are years away from declaring winners and losers. The best technology today only has dozens or a few hundred qubits. If the United States government were to pick a "winner" quantum modality, it would be a significant gamble and risk crippling promising technologies that are not yet fully developed. Supporting all modalities equally is the best way to ensure a robust and productive quantum ecosystem where development can be accelerated.

National Quantum Initiative:

Question 3. What goals should the Committee consider in reauthorizing the National Quantum Initiative?

Answer. Congress and the Administration have taken significant and very wise initial steps to recognize the power and potential of quantum science and engineering advancement and the out-sized role such progress will have for all aspects of our society. The bipartisan National Quantum Initiative Act of 2018 was an excellent step requiring a government plan to accelerate quantum science and engineering development in a coordinated and strategic fashion.

Four areas that would be valuable for the Committee to consider are workforce development, manufacturing support, more centralized organization of quantum programs within the government, and streamlined acquisition processes that encourage quantum technological development.

The quantum industry is growing rapidly, and its workforce needs to grow with it. To encourage students to pursue careers in the quantum industry, we need to make quantum education more accessible. Offering funding to high schools and community colleges to develop quantum educational programs, particularly with affordable access to cloud-based quantum computers and quantum matter machines, will ensure that students get early exposure to quantum science. Students studying quantum-related fields could be offered scholarships, and workers who spend several years within the quantum industry, particularly for technician-level jobs, could be offered loan forgiveness to encourage their participation in the quantum workforce.

In the interest of economic growth and national security, we urge the Committee to take steps to support a robust domestic supply chain. By investing in small, domestic manufacturers, we can build that secure supply chain and provide high-paying jobs for Americans.

We also urge the Committee to continue its leadership role by encouraging key government departments and agencies to move more quickly to tailor internal organizational practices in recognition of the critical strategic importance of quantum development. Departments and agencies must move swiftly and decisively to adopt detailed program planning, budgeting, and program acquisition policies/procedures to accelerate quantum-based technology advancement. This includes creating a centralized system to plan, track, monitor, assess, and ensure high payoff developments are sufficiently resourced for all viable quantum science R&D projects across the Department/agency enterprise. It also entails the establishment of effective mechanisms for Federal agencies to share/coordinate quantum R&D activity plans and results to maximize the speed and quality of quantum development.

We urge the Committee also to consider legislation to encourage departments and agencies to modify their program acquisition procedures expressly to allow for the insertion of viable quantum technology solutions. Since we are early in the quantum technology development cycle, prime contractors should not be penalized or discouraged for proposing to accept higher risk/higher reward quantum technology solutions in the acquisition selection and contract negotiation processes. Departments and agencies should not penalize contractors for accepting cost and schedule risk for the inclusion of highly promising quantum solutions, given the strategic importance to the Nation of accelerating the development and maturation of this high-payoff technology.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KYRSTEN SINEMA TO DR. BOB SUTOR

STEM Education in CHIPS and Science Act: The bipartisan CHIPS and Science Act authorized $13 billion over five years for the National Science Foundation (NSF) to put towards Science, Technology, Engineering, and Mathematics (STEM) education. The legislation directs the NSF to explore opportunities to engage students from groups historically underrepresented in STEM fields as well as rural areas to expand the pipeline to help ensure the United States has the STEM workforce we need for the Twenty-First Century.

Question 1. How will the CHIPS and Science legislation expand STEM education and, in turn, America's STEM workforce? Why is it important for Congress to fund the investments in STEM education made in the legislation?

Answer. The provisions in the CHIPS and Science legislation will go a long way toward strengthening and diversifying America's STEM education and workforce. These provisions will require Federal agencies and universities to identify and lower barriers to the recruitment, retention, and advancement of women, minorities, and other underrepresented groups in STEM. They will also require much-needed data collection on the demographics of the STEM workforce, provide insights on reasons for poor recruitment and retention, and inform best practices for making the STEM workforce inclusive. Funding these provisions will yield valuable gains in the development of our STEM workforce and accelerate its diversification.

We agree with the provisions and requirements in the Chips and Science Act—Title V: Broadening Participation in Science document at *https://science.house.gov/imo/media/doc/STEM percent20Participation.pdf.*

Semiconductor Investments: Once the global leader, America now only accounts for approximately 12 percent of the world's semiconductor manufacturing. Recognizing this important national security issue, I worked with my colleagues to ensure the CHIPS and Science Act also appropriated $52 billion for the Commerce Department to establish grants to jump-start investments in America's domestic semiconductor industry. These investments will support tens of thousands of Arizona jobs at facilities managed by Intel, TSMC, and other Arizona semiconductor companies.

Question 2. How does the CHIPS and Science Act and the law's semiconductor investments illustrate the United States' commitment to being a global leader in this field and what further actions can be done to expand U.S. leadership in this field?

Answer. The CHIPS and Science Act takes bold and critical steps towards re-establishing a robust domestic semiconductor supply chain. Recent chip shortages have affected consumer goods, from cars to computers, mainly due to reliance on a highly homogenous, overseas supply chain. Investing in our domestic capacity to produce semiconductors will strengthen our national security, limit the economic distress that can result from supply chain problems, and, as you aptly note, create many high-paying tech jobs for Americans. But we should not stop there.

Many quantum enabling technologies are only available from a few small vendors, and many of those vendors are overseas. For our national security and economic growth, we must develop a robust domestic quantum supply chain by investing in small domestic manufacturers.

It is important to note that many quantum technologies are not packaged as "chips." While semiconductors are used in the control systems for cold atoms, ion traps, and photonic quantum devices, the computer or sensor may be within a glass cell, with lasers performing many functions.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. RAY BEN LUJÁN TO DR. BOB SUTOR

Development of Quantum Sensors: Dr. Sutor, you noted in your testimony that sensors are a near-term application of quantum technologies. You cite inertial sensors and clocks as particularly useful implementations that soon could be fielded and commercialized. Our National Laboratories are leaders in the field of quantum engineering. For example, Sandia's Quantum Information Program has improved our understanding and mastery of quantum systems, enabling cutting edge sensor systems. Congress dedicated significant resources to the expansion of quantum technologies in the CHIPS and Science Act.

Question 1. Yes or No, should we be leveraging our National Lab's assets and expertise to rapidly mature and commercialize these emerging technologies?

Answer. Yes.

Question 2. How can we better support public-private partnerships to accelerate the development of promising sensing applications?

Answer. We urge the Committee to consider legislation to encourage departments and agencies to modify their program acquisition procedures expressly to allow for the insertion of viable quantum technology solutions. Since we are early in the quantum technology development cycle, prime contractors should not be penalized or discouraged for proposing to accept higher risk/higher reward quantum technology solutions in the acquisition selection and contract negotiation processes. Departments and agencies should not penalize contractors for accepting cost and schedule risk for the inclusion of highly promising quantum solutions, given the strategic importance to the Nation of accelerating the development and maturation of this high-payoff technology.

We should specifically look at how the public-private partnerships can accelerate the time from prototype to system-of-record for higher-precision atomic clocks, inertial sensors, and Radio Frequency receivers. It's not enough to develop the individual components and sub-components of quantum computers, quantum sensors, and quantum communication equipment. The partnerships should aim to create complete solutions that can be quickly commercialized.

The most critical gap in the development of quantum sensing applications is the scalable manufacture and assembly of these complete systems. The manufacture of the core photonic and quantum components has been demonstrated, and the assembly technologies are available. An ideal, shovel-ready public-private partnership is to build out these demonstrated capabilities as a flexible, for-profit service. The service will support the critical manufacturing needs of the quantum sensor industry as it develops while producing the core assemblies for commercial quantum products.

Question 3. Where do you anticipate that quantum sensors may be most useful? You cite GPS systems as a vulnerability that could be mitigated using quantum sensors. Would these efforts make our Nation more secure?

Answer. Quantum technology will give us next-generation navigation with the highest possible precision. There is no scale of resolution finer than quantum. Our current GPS has several weaknesses. GPS signals can be affected by weather and other atmospheric conditions. More significant problems, especially for those concerned with security, are "GPS jamming" or "denial," where a signal is turned into noise, or "GPS spoofing," where a valid signal is replaced by a stronger and nefariously incorrect one. You don't want to be on a plane that thinks it is hundreds of miles away from its actual location. This practice is known and common in war zones, and denial or spoofing of GPS in a major city could snarl much of its transportation with apparent implications for safety and commerce.

Financial transactions and cellular and power infrastructure are dependent on GPS. Financial transactions across networks use GPS for timestamping. Accuracy is essential in high-speed applications to know the exact sequence of transactions. Cellular base stations can use GPS to synchronize their times to use the broadband spectrum more precisely. Power networks are complicated these days, with multiple energy sources and, often, bidirectional flow. Time synchronization from GPS is used in some grids to optimize and balance electricity distribution.

Quantum atomic clocks combined with quantum inertial sensors will be able to provide what is, in effect, onboard dead reckoning. There will be no need to connect to satellites or external sources that can be blocked or manipulated. We will likely migrate to this kind of quantum-based solution for PNT—Positioning, Navigation, and Timing. This technology will be useful to the warfighter and make our Nation more secure; the military and defense will most likely be the first users of these solutions. But, like GPS, businesses will be able to develop commercial products, and we could use them in our everyday lives, such as in fully autonomous self-driving cars that cannot lose signal in tunnels or bad weather.

Quantum atomic clocks are already used today in GPS satellites, and they will eventually become pervasive elsewhere as they become smaller and less expensive. They will appear in our network, cloud data centers, cell phone towers, ATMs, planes, and ships, as well as in our cars and phones. Not only will they operate independently or in ensembles and be highly accurate, but they will also maintain that accuracy for weeks or months before resynchronizing.

Beyond PNT, quantum sensors will have many uses that will make our Nation more secure. For example, quantum Radio Frequency (RF) sensors are significantly more sensitive than traditional ones and will enable warfighters to detect RF signals that are undetectable today. We can even measure gravity fluctuations with quantum gravimeters. These can determine changes in the earth's density and help discover new resources. Other applications include safety and recovery operations, such as finding voids in building collapses after an earthquake, or, more salient to national security, discovering underground structures or tunnels that adversaries may have constructed out of sight. We might even get early alerts for natural disasters such as landslides and sinkholes.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. RAPHAEL WARNOCK TO DR. BOB SUTOR

Workforce Diversity:

Question 1. What is the importance of fostering greater diversity within America's science, technology, engineering, and mathematics (STEM) workforce, and to what extent would failure to diversify our workforce hinder our national and economic security?

Answer. The workforce needs of the quantum industry are growing as rapidly as the industry is. To meet these needs, we cannot afford to overlook people of talent who have been historically underrepresented in quantum physics, particularly women and people of color. Embracing all forms of diversity as we grow the quantum workforce will not only maximize the pool of talent but having a diverse workforce is highly beneficial in the workplace in terms of productivity, creativity, and problem-solving. ColdQuanta is dedicated to building a diverse quantum workforce with internal education efforts to ensure we provide a highly inclusive work environment and external efforts aimed toward equitable recruitment and hiring practices. Diversity is an important value that will make our domestic quantum workforce stronger and more competitive globally.

The United States needs the best talent to compete economically and ensure that we always have the most advanced technology for our national security. The coming quantum era will require a broad range of skills, talents, and backgrounds to secure our success. We commonly hear about academic and industrial research results from those with doctorates. For quantum to become pervasive and practical, we need hardware and software engineers, technicians, and manufacturing workers. Quantum and classical computing will co-exist. While some people working in traditional computing will develop quantum skills, we should primarily consider the new talent we need for the very different aspects of quantum. Our needs will only add to whatever shortcomings we have now. Those needs are diverse, as must be the people who fulfill them.

Question 2. What role do historically black colleges and universities (HBCUs) and other minority-serving institutions play in helping to build a diverse workforce? What lessons can universities and other institutions draw from the success of HBCUs in supporting our STEM workforce?

Answer. According to a 2019 paper in the Educational Researcher journal,[1] "STEM is the only field where Black and Latina/o youth are significantly more likely than their White peers to switch and earn a degree in another field." Since quantum technology is so different from its classical counterpart, now is the time to remedy the STEM disparity regarding diversity and inclusion. We have a new opportunity to "do it right." We can build a diverse workforce in a novel industry, close the STEM participation gaps for quantum, and keep people in the field. Quantum is not just physics: its study includes mathematics, computer science, chemistry, and engineering, and it has applications in AI, materials science, logistics, finance, and any field that uses optimization techniques. HBCUs can teach quantum as a multidisciplinary field that better reflects the broad range of jobs that will be available in the industry.

Providing a high standard of quantum education does not need to be burdensome in terms of time or resources for the faculty offering it. Students, professors, and researchers can access quantum computers and emulators via the cloud. There is no need to install a quantum system locally. For example, ColdQuanta will offer quantum matter machines and quantum computers on the cloud. With them, users will be able to create ultra-cold quantum matter or perform quantum calculations remotely. Further, much of the software for using quantum computers is open source, such as Cirq and Qiskit. The essential resources for learning about and using quantum computers are available from our rural areas to our biggest cities.

Rural Institutions: Georgia is a proud agricultural state, and I am particularly excited for how advanced technologies will help improve precision agriculture and otherwise support America's farmers. I am concerned, however, by the underrepresentation of rural students and rural colleges and universities among America's leading research institutions and the effect this will have in fields such as precision agriculture.

Question 3. What barriers do rural students face in entering the workforce in advanced technologies such as artificial intelligence and quantum computing? How can Congress help address these barriers?

Answer. Access is a significant barrier to entry for the rural student. In the past, to do quantum science or receive quantum education, you had to be physically present in a laboratory, but not anymore. The remote availability of quantum computers and emulators via the cloud makes quantum science much more accessible. Open-source software and online courses make it easier for the rural student to learn quantum science and for faculty at rural institutions to offer such education.

Internships are crucial to getting practical experience and demonstrating proficiency in STEM areas like AI and quantum. During the pandemic, many internship programs were virtual, and students could participate from anywhere. Now, fewer remote internships are available, and there is often an assumption that face-to-face is required. In some cases, such as hardware, one must be where the facilities are. For software, while "back to the office" may be advantageous, it has disadvantages for those who cannot travel.

Congress can help address the barriers for rural students by:

- ensuring equitable cloud access to quantum computers and emulators for students, faculty, and researchers,
- ensuring that U.S. government labs and agencies offer virtual options for internships whenever possible,
- fully reimbursing students for all reasonable travel and living expenses when temporary relocation for an internship is necessary,
- offering scholarships for students who choose to pursue quantum education and loan forgiveness for students who go to work in the quantum industry; and
- encouraging commercial organizations to consider students from a broad range of geographic locations.

While K–12 curricula are usually in the domain of the states, education on quantum technologies and data science should extend downward into high schools. National educational standards for the technologies most important to our economic and security interests should be considered. High schools in rural areas should be supported by training educators and giving students low-cost access to learning materials and cloud-based technology.

Question 4. What barriers do rural colleges and universities and their faculties face in accessing and supporting research-related advanced technologies such as ar-

[1] "Does STEM Stand Out? Examining Racial/Ethnic Gaps in Persistence Across Postsecondary Fields." *https://journals.sagepub.com/doi/full/10.3102/0013189X19831006?journalCode=edra*

tificial intelligence and quantum computing? How can Congress help address these barriers?

Answer. A significant barrier for rural institutions and faculties is cost. To become proficient in and help develop leading-edge technology, one must have access to leading-edge technology. State-of-the-art research and graduate work in physics and engineering require investment in the equipment necessary. However, establishing and fully equipping a quantum science laboratory is time-consuming and expensive. With cloud-based solutions, this is not always necessary, and many of these costs can be avoided and time saved. Congress must ensure that access to cloud-based AI and quantum computing software is available and funded for research and education at rural institutions. Congress can also direct agencies like the National Science Foundation to fund quantum projects and equipment and develop quantum programming at rural schools.

Another possibility is to institute a more aggressive "rotating scholar" program where professors and researchers from less rural and academically higher-ranked institutions visit the rural colleges and universities for at least one term. These visiting positions exist today but could be increased five to tenfold to accelerate AI, quantum research, and education at rural institutions.

Global Collaboration and Competition: I have long believed that America must invest in innovation and advanced technologies to maintain our global standing. I am deeply alarmed that our global competitors, such as the Chinese Communist Party, have heavily invested in technology research and used it to oppress its own people and bolster autocratic regimes throughout the world. To keep America on the leading edge, Congress must strike the appropriate level of controls on innovation and intellectual property to protect our national and economic security without overly hindering scientific innovation and international collaboration.

Question 5. What are the key concerns that Congress should keep in mind as we work to achieve this balance? Please share any examples of Federal programs that you believe do not strike the right balance.

Answer. I agree that striking the right balance is critical. At one extreme, some could say, "control everything that might pose a threat anywhere in its future development." At the other extreme, some might want to sell as much as possible to anyone who wants a technology to reap the economic benefits. But neither extreme makes sense, and you are correct that as we develop export controls as a nation, we need to find the sweet spot or the natural balance point.

In the case of quantum computing technology, we can ask, "how large and powerful a quantum computing machine can we sell internationally without endangering our national security?". It's not an easy question to answer. Academics and industrial researchers are starting to build quantum computers from various core qubit technologies, including cold atoms, ion traps, superconducting, and photonics. There are seven or eight characteristics that play off against each other and make it difficult to know which approach will ultimately be best to scale for which supplication. To enable and support a diverse and productive quantum ecosystem, Congress must ensure that U.S. Government support does not favor one of these technologies over another because a lack of neutrality could preemptively stall valuable technological advances.

We are beginning to understand how large and "good" a quantum computer will need to be to break encryption, a possible eventual threat to cybersecurity. Less well understood is how we will connect small quantum "cores" with hundreds to thousands of qubits to create systems with hundreds of thousands of qubits. This problem is challenging because adding more qubits is unlike adding more memory to a laptop, for example. One doesn't just plug in a hundred more qubits to get a more powerful system.

In its deliberations on future legislation, such as the renewal of the 2018 National Quantum Initiative, Congress must call out the need for domestic development of these "quantum interconnects" between cores. Additionally, this legislation should call out the need for R & D to understand how several quantum computers might be networked to create larger systems that could defeat the intent of export controls.

RESPONSE TO WRITTEN QUESTION SUBMITTED BY HON. MARIA CANTWELL TO HENRY L. JONES II, PH.D.

Question. In your written testimony, you emphasize the need to attract more diverse people into STEM, including through industry certifications. What workforce difficulties did you see at your company and what more can universities do to relieve these issues?

Answer. For companies like mine that were competing and growing in global technology markets, the most significant obstacle to success was finding, recruiting, signing, and keeping exceptionally talented technology experts. Capability and availability were the most important decision factors by far. Diversity was a highly desirable outcome, but was hampered by our market realities—we would take the qualified hires we could get.

In addition, many companies have internal programs to improve recruiting by giving bonuses to its employees who can bring in a capable hire. This practice tends to result in a workforce with self-reinforcing demographics, which can significantly impact diversity over time, especially when compounded with the experience these employees gain by their initial employment.

Finally, I noticed that often the applicants from communities of color did not appear to have had opportunities to develop an impressive work portfolio and useful experience while a student. Rather than working as an intern applying their newly learned technical skills, they had been filling non-technical roles as work study students in university administration offices making copies and shuttling mail around campus.

The most successful solution that I have is seen for these difficulties was our creation of a standing internship and work/study co-op program with nearby universities to connect high potential juniors and seniors. This allowed the university and my company to engage students very early in their educational process, to connect them to role models, to give them insight into the utility of their classes, and to give them solid work experience to include in their portfolios to present to future employers. We usually brought these students in as full-time employees after graduation, but even those that we did not eventually employ presented positive experiences for the students and for our company.

Congress could dramatically increase the impact of such programs by providing cost-share frameworks, creating matchmaking resources, and supporting any efforts to educate parents in communities of color of the potential of technical careers for their children and the steps along the path to get them there.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. KYRSTEN SINEMA TO HENRY L. JONES II, PH.D.

STEM Education in CHIPS and Science Act: The bipartisan CHIPS and Science Act authorized $13 billion over five years for the National Science Foundation (NSF) to put towards Science, Technology, Engineering, and Mathematics (STEM) education. The legislation directs the NSF to explore opportunities to engage students from groups historically underrepresented in STEM fields as well as rural areas to expand the pipeline to help ensure the United States has the STEM workforce we need for the Twenty-First Century.

Question 1. How will the CHIPS and Science legislation expand STEM education and, in turn, America's STEM workforce? Why is it important for Congress to fund the investments in STEM education made in the legislation?

Answer. Rural students are generally unlikely to have direct exposure to cutting-edge technologies and are even less likely to learn the methods by which they are developed. This exposure comes from visits to high-tech companies, presentations by role models in their communities, and projects that give them hands-on experience with the related tools and concepts. The CHIPS and Science legislation is of interest to rural states' workforce and industry development because the expertise areas of individuals, academic teams, and companies that are needed to create advanced new products and services in rural areas will be uncommon.

Congress could help address these barriers by supporting activities that provide educational opportunities to students and to their parents regarding the career potential of these advanced technologies. Congress should also ensure that some of the societal and economic forces that lead to centralization of innovation—personnel and equipment and infrastructure—are not explicitly or implicitly reinforced by its policies. The component of the CHIPS Act that emphasizes the participation of EPSCoR states in the regional technology hubs is an excellent example of what Congress can do to provide long-term investment in rural-oriented development of advanced technologies. Support for workforce development in rural communities focused on developing and keeping opportunities for advanced technology-related employment is also something Congress should continue to make a priority.

Semiconductor Investments: Once the global leader, America now only accounts for approximately 12 percent of the world's semiconductor manufacturing. Recognizing this important national security issue, I worked with my colleagues to ensure the

CHIPS and Science Act also appropriated $52 billion for the Commerce Department to establish grants to jump-start investments in America's domestic semiconductor industry. These investments will support tens of thousands of Arizona jobs at facilities managed by Intel, TSMC, and other Arizona semiconductor companies.

Question 2. How does the CHIPS and Science Act and the law's semiconductor investments illustrate the United States' commitment to being a global leader in this field and what further actions can be done to expand U.S. leadership in this field?

Answer. The economic drivers that led to the global distribution of semiconductor expertise and facilities are significantly impacted by national and international agreements for trade and intellectual property protection. The CHIPS and Science Act is a substantial action by the United States to recognize this reality, and to take steps to set long-term conditions towards a healthy domestic semiconductor industry.

One area in which Congress might take additional action could be the sensitive issue of immigration, particularly how we attract, welcome, and keep the most innovative and energetic individuals, companies, and communities from around the global semiconductor industry as American citizens—to integrate them instead of competing with them. Many of our most successful technology companies (*e.g.,* Google) were created by immigrants. Rural areas have very low cost of living and excellent telecommunications and transport connectivity. Congress would be wise to implement immigration policies that encourage global entrepreneurs to move to rural areas.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. RAPHAEL WARNOCK TO HENRY L. JONES II, PH.D.

Workforce Diversity:

Question 1. What is the importance of fostering greater diversity within America's science, technology, engineering, and mathematics (STEM) workforce, and to what extent would failure to diversify our workforce hinder our national and economic security?

Answer. While the wisdom of diversity is commonplace in investment circles—the positive economics inherent in diverse portfolios are well known (even warranting a Nobel Prize for Harry Markowitz)—this same insight has only recently been recognized by U.S. technology industry decision makers. Whether the concern is how a lack of diversity might make the company and its workforce pipeline more fragile by "putting all its eggs in one (or just a few) baskets," or through the blindness to potential threats and opportunities due to a limited set of perspectives, I have witnessed a complete change in mindset over my career from a disregard for diversity to a highly intentional appreciation for it at all levels of technology company management.

At this stage, Congress can support this mindset by taking whatever steps available to it for the further diversification of our STEM workforce—steps that will be supported by the tech industry. If we as a nation do not do so, we will undermine our industrial base, our socioeconomic fabric, and our foundation for future growth.

Question 2. What role do historically black colleges and universities (HBCUs) and other minority-serving institutions play in helping to build a diverse workforce? What lessons can universities and other institutions draw from the success of HBCUs in supporting our STEM workforce?

Answer. For many years, I was a part of the industry advisory board created by Jackson State University as it stood up its Computer Engineering department from scratch in the 2000s, and I watched the faculty and students rapidly grow professionally and academically. The obstacles and failures I watched them overcome, as well as the successes I saw along the way—and the lessons I drew from that experience—would fill many pages.

The most salient lessons were the critical importance of accessible role models and high standards, and their impact on student experience and workforce readiness. Jackson State University, as the HBCU I know best, had to make many difficult decisions as it created the culture of its new School of Engineering. HBCUs have an opportunity to promote world-class excellence in STEM that can have a high-profile impact across the technology ecosystem. For many engineering tasks, which impact public safety and well-being in myriad ways, "good enough" is not good enough—standards mean something. It seems to be an unfortunate truth that even almost 100 years later, the mentality of the Tuskegee Airmen—that they push themselves to be the best fighter pilots in the air because of their skin color—is still a societal dynamic that students of color must deal with. I saw my JSU colleagues use this challenge as an opportunity to push for a culture of the highest standards for their students, which raises the bar for STEM students everywhere no matter their socioeconomic background. I welcome further discussion that might help Senator Warnock with any efforts on this vital topic.

Rural Institutions: Georgia is a proud agricultural state, and I am particularly excited for how advanced technologies will help improve precision agriculture and otherwise support America's farmers. I am concerned, however, by the underrepresentation of rural students and rural colleges and universities among America's leading research institutions and the effect this will have in fields such as precision agriculture.

Question 3. What barriers do rural students face in entering the workforce in advanced technologies such as artificial intelligence and quantum computing? How can Congress help address these barriers?

Answer. Rural students are generally unlikely to have direct exposure to cutting-edge technologies in general, and even less likely to learn the methods by which they are developed. This exposure comes from visits to high-tech companies, presentations by role models in their communities, and projects that give them hands-on experience with technology-related tools and concepts. I agree wholeheartedly with Senator Warnock that these barriers have the potential to negatively impact technology topics of interest to rural states, such as precision agriculture, because the combination of related expertise areas by individuals, academic teams, and companies that are needed to create advanced new products and services in rural areas will be uncommon.

Congress could help address these barriers by supporting activities that provide educational opportunities to students and to their parents regarding the career potential of these advanced technologies. Congress should also ensure that some of the societal and economic forces that lead to centralization of innovation—personnel and equipment and infrastructure—are not explicitly or implicitly reinforced by its policies. The component of the CHIPS Act that emphasizes the participation of EPSCoR states in the regional technology hubs is an excellent example of what Congress can do to provide long-term investment in rural-oriented development of advanced technologies.

Question 4. What barriers do rural colleges and universities and their faculties face in accessing and supporting research related advanced technologies such as artificial intelligence and quantum computing? How can Congress help address these barriers?

Answer. The nature of high-growth, high-potential technologies is that there is often a "first mover advantage" in many ways—as interest grows in a topic, those who have established themselves as the experts can attract outsized attention and new resources as others join in and try to get up to speed quickly. That leads to a self-reinforcing cycle in which the biggest keep getting bigger. If something new happens to get its start in a rural area, the draw of moving the effort to the additional resources of an urban area will be significant. Congress can help with this by recognizing this dynamic (often referred to as "power law" economics) and enacting policies to counter it when possible. For example, qualified regions or entities could receive related infrastructure investments (specialized lab facilities, targeted workforce development programs, etc) that would serve as anchors to keep innovation tied to specific locations. Support for workforce development in rural communities focused on developing and keeping opportunities for advanced technology-related employment is also something Congress should continue to make a priority.

Global Collaboration and Competition: I have long believed that America must invest in innovation and advanced technologies to maintain our global standing. I am deeply alarmed that our global competitors, such as the Chinese Communist Party, have heavily invested in technology research and used it to oppress its own people and bolster autocratic regimes throughout the world. To keep America on the leading edge, Congress must strike the appropriate level of controls on innovation and intellectual property to protect our national and economic security without overly hindering scientific innovation and international collaboration.

Question 5. What are the key concerns that Congress should keep in mind as we work to achieve this balance? Please share any examples of Federal programs that you believe do not strike the right balance.

Answer. Senator Warnock is right to be concerned about this troubling dynamic within our international competitive environment. In some cases, various Federal programs and entities might have taken longer than they should have to recognize this threat, but I do not currently see any who are acting as if they are unaware of their responsibility to protect American interests.

The area of greatest concern to Congress should be the sensitive issue of immigration, particularly how we attract, welcome, and keep the most innovative and energetic individuals, companies, and communities from around the globe as American citizens—to integrate them instead of compete with them. Many of our most successful technology companies (*e.g.,* Google) were created by immigrants. Rural areas have very low cost of living and excellent telecommunications connectivity. Congress would be wise to implement immigration policies to get global entrepreneurs to move to rural areas, where their impact will be greater and the social pressures to promote pro-American values and behaviors will be greater as well.

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