MAINTAINING U.S. LEADERSHIP IN SCIENCE AND TECHNOLOGY

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED SIXTEENTH CONGRESS

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March 6, 2019

MAINTAINING U.S. LEADERSHIP IN SCIENCE AND TECHNOLOGY

WEDNESDAY, MARCH 6, 2019

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
WASHINGTON, D.C.

The Committee met, pursuant to notice, at 2:35 p.m., in room 2318 of the Rayburn House Office Building, Hon. Eddie Bernice Johnson [Chairwoman of the Committee] presiding.

U.S. HOUSE OF REPRESENTATIVES
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HEARING CHARTER

Maintaining U.S. Leadership in Science and Technology

Wednesday, March 6, 2019
2:00 p.m. – 4:00 p.m.
2318 Rayburn House Office Building

Purpose

On Wednesday, March 6, 2019, the Science, Space, and Technology Committee will hold a hearing to assess the current state of U.S. science and technology (S&T) in the global context and what is needed to maintain U.S. leadership. The hearing will examine the role of federal investments in S&T; partnerships between academia, government and industry; the future of U.S. research universities; STEM education and the U.S. STEM workforce; and increasing international competition in areas of emerging technology as well as opportunities for increased international collaboration on pressing global challenges.

Witnesses

- **Dr. Marcia McNutt,** President, National Academy of Sciences
- **Dr. Patrick Gallagher,** Chancellor, University of Pittsburgh
- **Dr. Mehmood Khan,** Vice Chairman and Chief Scientific Officer, PepsiCo; and Chair, Council on Competitiveness

Overarching Questions

- Why is support for science, technology, and STEM education so critical to America's prosperity? What are the principal challenges the United States faces in these areas as it competes in the global economy?
- What is the role of the federal government in ensuring a thriving S&T enterprise? What is the role of the private sector? How can government and the private sector best partner to advance U.S. S&T?
- What are the benefits, risks, and challenges to international collaboration in S&T?
- What specific steps should the federal government take to ensure that the United States remains the world leader in science, innovation, and job creation?

Status of R&D and STEM Education - by the Numbers

U.S. investments in R&D

In 2015, the US performed a total of $491.5 billion of R&D. While the business sector is focused on applied research and development, the federal government has the largest role in basic research. In 2015, basic research comprised $83.5 billion (16.9 percent) of total R&D expenditures. Of that total, 27 percent was funded by the business sector compared to 44 percent by the Federal government. The business sector accounted for just over one-half of applied research, with more than one-third funded by the Federal government.

In terms of trends in U.S. R&D expenditures, in the seven-year period between 2008-2015, U.S R&D grew at a rate of 1.4 percent annually while GDP grew at a rate of 1.5 percent annually. The preceding ten-year period (1998-2008) featured average annual growth of 3.6 percent for R&D expenditures while GDP grew 2.2 percent annually.

Universities performed $41 billion in basic research in 2017 – nearly half of all basic research that year. Nearly $22 billion of that was federally funded. Only 5.3 percent was funded by business. Universities also performed $17.5 billion in applied research. Again, more than half of that was federally funded and only 6.3 percent came from business. While there has been a recent uptick in industry support for university research, universities have increasingly relied on foundations and their own institutional funds to support their research.

Decades ago, tech companies invested significantly more in basic research. The examples most commonly cited are Bell Labs and Xerox PARC. Nine Nobel awards were given for work completed at Bell Labs, but Bell Labs began its final decline in the 2000s and was shuttered altogether by 2008. Similarly, Xerox PARC no longer exists as such and its successor organization is focused on technology development with short-term returns. Company investment in internal basic research has increased somewhat in the last few years after the steep decline of the 1990s. In 2016 the total was $19.1 billion, compared to $16.3 billion just the year before. Total corporate basic research performance from all sources was $24.6 billion in 2016 - that includes federally funded research at companies. However, the U.S. pharmaceutical industry alone accounts for one-third of corporate basic research. Similarly, philanthropic support for research has been on the rise, but it is overwhelmingly focused on biomedical research. There are a few tech companies, including Google and Uber, who have been investing heavily in basic and applied research, internally and at universities. Their scientists do publish some of their research findings, but much of their research is proprietary.

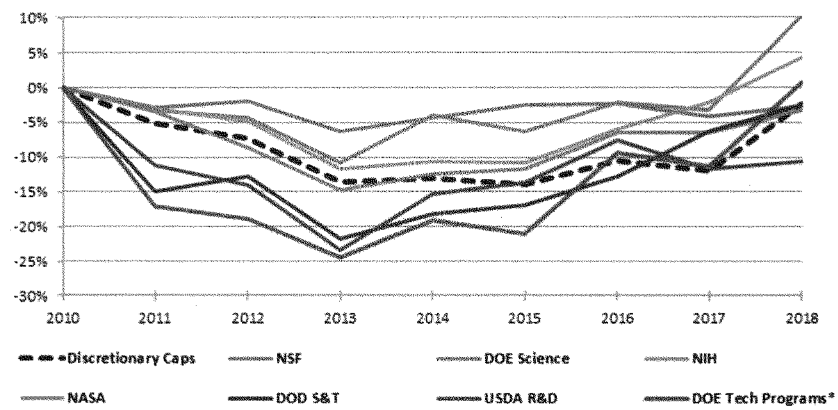
There are many partnerships between the government, universities, and the private sector, and the Science Committee often explores the nature of those partnership models - what works, what can be expanded, and what new models may be viable. However, those partnerships require a sustained commitment by all parties. Private sector money most often comes *because* the federal money is there. The private sector relies on the quality and imprimatur of the federal science agencies' merit-review processes to identify the most promising research.

Federal Government Investments in R&D

Support for R&D as a percentage of the nondefense discretionary budget has held mostly steady at just over 10 percent since the 1990's, but the total size of the nondefense discretionary budget has been under pressure. Under the 2018 budget deal, that budget has increased from 2017 levels but is still below the 2010 level. The budget caps required under the 2011 budget deal magnify the challenge for R&D funding, unless lifted once again.

The graph below from the AAAS R&D Budget Analysis underscores the loss of buying power at most of our federal science agencies over the last decade. The data are presented relative to 2010 constant dollars. The year 2010 was the second year of the American Recovery and Reinvestment Act, so it saw an unusual increase in R&D expenditures, second only to 2009. However, even with 2011 as the baseline, the trend lines are sobering. In 2018, the National Science Foundation had the same buying power it did in 2011. Other agencies took bigger dips along the way but are better off than they were in 2011. Congress has done well by NIH and DOE in recent years, not so with USDA. NIST, which isn't on the chart, has done better than inflation, but not enough to support the expanded scope of their work during that period. The Trump Administration proposed drastic cuts to federal R&D in FY 2018 and 2019. Congress took a different approach in both years. We have not yet seen the FY 2020 budget proposal, but we have been told to expect similar cuts again this year.

Figure 3: Federal S&T Agency Spending Since FY 2010
Percent change in discretionary budgets from FY10 levels, constant dollars



*Including nuclear, fossil, grid research, renewables, and efficiency.
Based on AAAS analyses of historical OMB, agency, and appropriations data. © 2018 AAAS

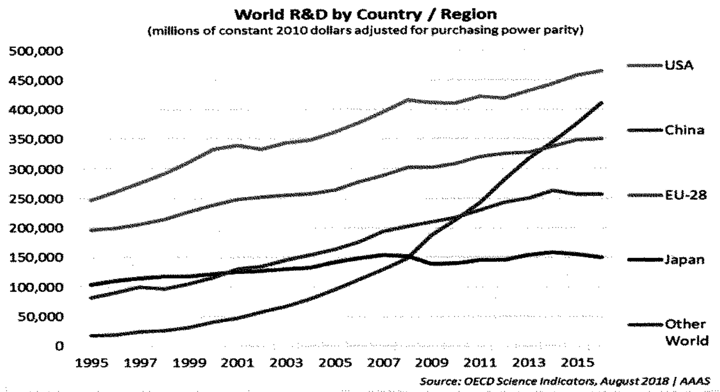
There are suggestions in some corners that the private sector can pick up the difference as the federal government retreats from its previous level of commitment to research. While, as noted previously, there has been some uptick in private sector funding for basic research, the increase does not begin to account for the loss of buying power from the federal government. And the nature of that funding source is such that the research questions themselves are more constrained. Nor is there any realistic path for a return to the Bell Labs model of yesteryear. Corporations, quite simply, are focused on shareholder returns, so research can no longer be central to their mission. Only a few select companies stand out as exceptions to this rule. In the meantime, university researchers are struggling. They spent a significant portion of their time applying for grants from programs with pay lines as low as 10 percent. Further, U.S. research infrastructure is crumbling. Many of our National Lab facilities are 50-60 years old. The same is true on many university campuses. Today's STEM students see these trends and worry about their own future careers in research, or decide outright to leave research or to go abroad where research money is more readily available and facilities more cutting edge. Partnerships with the private sector are important. But for the U.S. to maintain its leadership in S&T, the U.S. government must remain committed to supporting research.

International Competition

Around the world, global R&D funding has been increasingly rapidly, growing more than two and a half times between 2000-2015. In that time frame, the U.S. has shifted from making up 37 percent of global R&D expenditure in 2000 to 26 percent in 2015. The US now ranks 11th in the world in research intensity behind Germany, Taiwan, and South Korea. Further, as a share of GDP, the U.S. is close to dropping out of the top 10 in basic research expenditures.

Between 2005-2016, Germany, South Korea, China, and Taiwan have all increased total R&D spending as a portion of GDP. R&D investments are continuing to shift to countries in East Asia; South Korea doubled R&D expenditure between 1995-2014 to reach 4.3 percent of GDP. In the same time frame, China has increased R&D expenditure as a portion of GDP from 0.64 percent to 2.05 percent, with a plan to spend 2.5 percent of GDP by 2020. The National Science Board predicts China will overtake the U.S. in R&D by the end of 2018.

The U.S. spends more on health R&D than all other OECD countries but ranks near last in agriculture, energy, and environment R&D spending. In areas of emerging technology that will have significant economic and security consequences, the U.S. risks falling behind. Other countries have clear national strategies and large coordinated investments in biotechnology and quantum science and engineering. The UK government has made synthetic biology a national priority since at least 2012. China has also developed an aggressive strategic roadmap in biotechnology, especially in agricultural biotechnology. The EU and China have both made significant commitments in quantum science and engineering, with China building a $10 billion research center for quantum applications. The U.S. is only now putting in place a national strategy for quantum science and engineering, and does not yet have one for engineering biology. The race is on in artificial intelligence as well. In 2017, China's government announced a goal of becoming a global leader in artificial intelligence by 2030. The Trump Administration recently issued an executive order directing science agencies to prioritize AI R&D and is working on developing a research strategy through the National Science and Technology Council. However, even with a strategy in place, funding has to follow to realize the benefits and guard against the security risks.



STEM Education and the Workforce

K-12 Statistics -

The National Assessment of Educational Progress (NAEP) mathematics assessment results show that average mathematics scores for fourth, eighth, and twelfth graders declined slightly for the first time in 2015 and remained flat or showed only small gains between 2005 and 2015. Less than half of fourth, eighth, and twelfth grade students achieved a level of proficient or higher on NAEP mathematics and science assessments in 2015.

In the international context, the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA) 2015 data show that the U.S. average mathematics assessment scores were well below the average scores of the top-performing education systems.

Average scores on 2015 NAEP mathematics and science assessments for fourth, eighth, and twelfth grade students who were eligible for free or reduced-price lunch (an indicator of socioeconomic status) were 23 to 29 points lower than the scores of their peers who were not eligible for the program. Score differences between students eligible for free or reduced-price lunch and those who were not persisted within racial or ethnic groups. Performance gaps between white students and black and Hispanic students showed similar patterns across all NAEP assessments and grade levels, with average scores of white students at least 18 points higher than those of Hispanic students and at least 24 points higher than those of black students. Gaps between male and female students on NAEP mathematics and science assessments were small, with average score differences of two to five points in favor of male students.

Higher Education Statistics -

In 2015, underrepresented minority groups comprised 39 percent of the college-age population of the U.S., but only 22.5 percent of students earning bachelor's degrees in STEM fields. U.S.

citizen and permanent resident underrepresented minorities earned only 14 percent of STEM doctorate degrees awarded in 2015. By 2050, underrepresented minorities will comprise 52 percent of the college-age population of the U.S.

Women now earn about half of all STEM bachelor's and doctoral degrees, but major variations persist among fields. In 2015, women earned only 20 percent of all bachelor's degrees awarded in engineering and computer sciences and 40 percent in the physical sciences and mathematics. Similarly, they earned less than one-third of the doctorates awarded in mathematics and statistics, computer sciences, and engineering.

Workforce Statistics -

The majority of scientists and engineers – all individuals trained or employed in STEM - are employed in the business sector (71 percent), followed by the education (19 percent) and government (11 percent). The skilled technical workforce – those who use S&E expertise in their jobs but do not have bachelor's degrees- account for a substantial component of the U.S. STEM workforce. The STEM workforce is aging. The median age of scientists and engineers in the labor force was 43 years in 2015, compared to 41 years in 1995.

In 2015, women constituted 50 percent of the college-educated workforce, 40 percent of employed individuals whose highest degree was in a STEM field, and 28 percent of those in STEM occupations. However, there is significant variation across fields. Women are represented in relatively high proportions in social sciences (60 percent) and life sciences (48 percent) and relatively low proportions in engineering (15 percent), physical sciences (28 percent), and computer and mathematical sciences (26 percent).

In 2015, underrepresented minorities accounted for only 15 percent of STEM highest degree holders and 11 percent of all workers in STEM occupations. Further, minorities accounted for only 13.5 percent of STEM degree holders employed in computing jobs. Based on the Bureau of Labor Statistics data, jobs in computing occupations are expected to account for 60 percent of the projected annual growth of newly created STEM job openings in the period from 2016-2026.

If the percentage of female students and students from underrepresented minority groups earning degrees in STEM fields does not significantly increase– and particularly in fields such as computing and data science - the United States will face an acute shortfall in the overall number of students who earn degrees in STEM fields just as United States companies are increasingly seeking students with those skills. With this impending shortfall, the United States will almost certainly lose its competitive edge in the 21st century global economy.

Data Sources -

All of the data in this memo are from the National Science Board's 2018 Science and Engineering Indicators, the AAAS Federal R&D Budget Trends Analysis, the OECD, or AAAS reporting of OECD data.

Chairwoman JOHNSON. Committee will come to order. Before I begin my opening statement, let me just apologize for being late. We were on the floor, and I know that there are Members en route, and I'll try to get my breath so we can get started.

Good afternoon, and welcome to our distinguished panel of witnesses. We called you here today because of your decades of collective experience and wisdom about the U.S. science and technology (S&T) enterprise, and I look forward to learning from you. I've always said that there is no more important Committee in Congress than the Science Committee when it comes to determining our Nation's future. In this Committee, we have an opportunity to look beyond the politics of today to develop the best policies for tomorrow. This afternoon the Committee will discuss key opportunities and challenges as we develop legislation, and lead discussions within Congress, on what we need to do to secure our future prosperity.

We will hear about the current state and history of S&T enterprise, the increasing international competition, and what that means to our economic and national security, how we can best educate and train a skilled workforce for the 21st century, and how the government, universities, and private sector can best partner to maintain U.S. leadership. According to data reported by the National Science Foundation (NSF), the U.S. now ranks number 11 in the world in research intensity. We are behind several countries in R&D (research and development) as a share of the GDP. China has surpassed us in total research publication output, and East Asian countries as a group have surpassed the U.S. In total number of R&D dollars invested, the U.S. was still leading in 2016, which is the latest data that the NSF has reported, but China likely surpassed us last year.

It has also been a given that the U.S. leads in investments in fundamental research at our universities and national labs, but we are close to dropping out of the top ten, even in basic research investments. The numbers are sobering, but they don't tell the full story, so I look forward to hearing from our experts about what this all means.

When we look at the state of STEM (science, technology, engineering, and mathematics) education and STEM workforce in the U.S., we also have cause for concern. Our students have not shown improvements in math or science assessments in the last decade, and they continue to perform well behind the average for top-performing countries internationally. There are significant achievement gaps across economic, and racial, and ethnic lines. The underrepresentation of minority groups persists through STEM-degree attainment, and participation in the STEM workforce. While women are doing much better than they used to, they continue to be significantly underrepresented in fields key to U.S. competitiveness, including computing and engineering. There is high demand for STEM skills that don't require a 4-year degree, but there is still a stigma associated with these jobs, even though they pay well.

By 2050, today's minorities will be the majority. Simple math tells us that if we do not increase the number of women and minorities earning STEM degrees and participating in the STEM workforce at all levels, we will experience dire workforce shortfalls in the not-too-distant future.

Some companies in the technology sector tell us that the shortfall is already here. I'm an optimist. These numbers are cause for concern, but we should also view them as a rallying cry for action. Our children and grandchildren are counting on us. We have many ideas on our agenda already, but I'm sure today's hearing will give us more. I'm confident that we will hear good ideas from the scientific experts, and from my colleagues on both sides of the aisle, and I look forward to today's discussion.

[The prepared statement of Chairwoman Johnson follows:]

Committee on Science, Space, and Technology

Opening Statement
Chairwoman Eddie Bernice Johnson
Maintaining U.S. Leadership in Science and Technology
March 6, 2019

Good afternoon and welcome to our distinguished panel of expert witnesses. We called you here today because of your decades of collective experience and wisdom about the U.S. science and technology enterprise, and I look forward to learning from you.

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According to data reported by the National Science Foundation, the U.S. now ranks 11th in the world in research intensity. We are behind several countries in R&D as a share of GDP. China has surpassed us in total research publication output and East Asian countries as a group have surpassed us in patents. In total number of R&D dollars invested, the U.S. was still leading in 2016, which is the latest data NSF has reported, but China likely surpassed us last year. It has also been a given that the U.S. leads in investments in fundamental research at our universities and national labs, but we are close to dropping out of the top 10 even in basic research investments. The numbers are sobering but they don't tell the full story, so I look forward to hearing from our experts about what this all means.

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I'm an optimist. These numbers are cause for concern, but we should also view them as a rallying cry for action. Our children and grandchildren are counting on us. We have many ideas on our agenda already, but I'm sure today's hearing will give us more. I am confident that we will hear good ideas from the scientific experts and from my colleagues on both sides of the aisle, and I look forward to today's discussion.

With that, I yield back.

Chairwoman JOHNSON. With that I yield back, and recognize Mr. Lucas.

Mr. LUCAS. Thank you, Chairwoman Johnson, for holding this important hearing on Maintaining United States Leadership in Science and Technology. Science and technology are central to America's national defense and economic security. Our Nation's founders understood that science was fundamental to our Nation's ability to prosper. Article 1 of the Constitution gave Congress the power to promote the progress of science. Americans are pioneers, and their spirit has always driven our support for science. In 1862, President Lincoln signed a land grant bill to fund a system of industrial colleges, one in each State, to conduct valuable research. I'm a proud graduate of one of those land grant institutions. He also signed the charter that created the National Academy of Sciences (NAS).

The 1930s, 1940s, and 1950s saw exponential increases in our scientific capacities, and the creation of the National Science Foundation, NASA (National Aeronautics and Space Administration), the Department of Energy, and the National Laboratories. Basic research forms the foundation of discoveries that fuel private-sector development and commercialization. It also provides a training ground for our Nation's scientists, engineers, and other STEM workers. Companies across the country are desperate for workers with skills to fill 21st century jobs. The United States is the world's largest research and development investor. U.S. Government and industry spent a combined $511 billion in 2016, generating over $860 billion for our Nation's economy, while supporting over 8 million jobs.

The basic research our government supports is foundational to our economic success. It allows us to stay at the forefront of cybersecurity, medical treatments, agricultural production, and technology exports. Government-funded research is translated into technology that supports our lives on a daily basis. For example, government supported research has given us a better understanding of the relationship between food production, water, energy, and making agriculture more productive. That benefits the farmers and ranchers in my home State of Oklahoma, of course, but it also improves our food supply, and reduces consumer food prices. A gene editing technique that allows for precise interventions that revolutionize healthcare by treating genetic disorders, and creating targeted cancer therapies. It also has the potential to improve our food supply by enhancing crop production, and improving livestock health.

Americans in every part of the country can access high-performing wireless networks thanks to the NSF-funded research, which provided the basis for 4G wireless communications. And Mammoth Trading, an online market system to lease water rights grew from NSF-funded research on groundwater pumping rights. Farmers now enjoy better risk management tools, lower costs for water reallocation, and increased productivity and improved water sustainability. I can go on and on, but I think it's clear that America's technology supremacy is a pillar of our economy.

Unfortunately, our dominance is under threat. China is narrowing the gap, and may surpass the United States in total R&D

spending this year. I believe the Federal Government has a responsibility to prioritize basic research and development, and this is not an easy task as we face enormous budget challenges, but it can be done. On a bipartisan basis this year, Congress supported $151.5 billion in Fiscal Year 2019 for Federal R&D, a 6 percent increase, and the highest point ever in inflation-adjusted dollars. As the Ranking Member of the House Science, Space, and Technology Committee, I'm committed to working with Chairwoman Johnson and the appropriators to continue to meet this challenge. To achieve this, however, I believe we need to collectively do a better job of explaining why science matters to all Americans. We need to break down the barrier between the ivory tower of academia, the hallways of Silicon Valley, and the Main Street of Cheyenne, Oklahoma.

My family has lived and farmed in Oklahoma for 100 years. When I look out my front porch, I can see a living laboratory of what science has done to improve American life. From the disease-resistant wheat that grows on my farm, to the vaccines that keep our cattle healthy, to the wind turbines on the horizon that provide a third of the State's electricity, these are real, tangible ways that science and technology have made our lives better. And it would not have happened without the longstanding government, academic, and industry research ecosystem that is the envy of the world.

I look forward to hearing from our distinguished panel of witnesses about how we can work together to meet this challenge, and to ensure that America continues to lead technological advancement. And with that, I yield back the balance of my time, Madam Chair.

[The prepared statement of Mr. Lucas follows:]

Lucas Opening Statement on American Competitiveness in Science and Technology

Mar 6, 2019
Opening Statement

Thank you, Chairwoman Johnson for holding this important hearing on "Maintaining United States Leadership in Science and Technology."

Science and technology are essential to America's national defense and economic security.

Our nation's founders understood that science was fundamental to our nation's ability to prosper. Article I of the Constitution gave Congress the power "to promote the Progress of Science."

Americans are pioneers and this spirit has always driven our support for science. In 1862, President Lincoln signed a land-grant bill to fund a system of industrial colleges, one in each state, that conduct valuable research.

I am a proud graduate of one of those land grant institutions. He also signed the charter that would create the National Academy of Science.

The 1930s, 40s and 50s saw exponential increases in our scientific capabilities and the creation of the National Science Foundation, NASA, the Department of Energy and the national laboratories.

Basic research forms the foundation of discoveries that fuel private sector development and commercialization. It also provides a training ground for our nation's scientists, engineers, and other STEM workers. Companies across the country are desperate for workers with the skills to fill 21st Century jobs.

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This is not an easy task as we face enormous budget challenges. But it can be done. On a bipartisan basis this year Congress supported $151.5 billion in Fiscal Year 2019 for federal R&D, a 6 percent increase and the highest point ever in inflation-adjusted dollars.

As the Ranking Member of the House Science, Space, and Technology Committee I am committed to working with Chairwoman Johnson and the appropriators to continue to meet this challenge.

To achieve this however, I believe we need to collectively do a better job of explaining why science matters to all Americans. We need to break down the barrier between the ivory tower of academia, the hallways of Silicon Valley, and the Main Street of Cheyenne, Oklahoma.

My family has lived and farmed in Oklahoma for over 100 years. When I look out my front porch, I see a living laboratory of what science has done to improve American life--from the disease-resistant wheat that grows on my farm, to the vaccines that keep our cattle healthy, to the wind turbines on the horizon that provide a third of the State's electricity.

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I look forward to hearing from our distinguished panel of witnesses about how we can work together to meet this challenge and ensure America continues to lead in technological advancement.

Chairwoman JOHNSON. Thank you very much, Mr. Lucas. We will now introduce our witnesses.

We have Marcia McNutt, President of the National Academy of Sciences. She has a Bachelor's in Physics from Colorado College, a PhD in Earth Sciences, Scripps Institute of Oceanography, and is a geophysicist, and the 27th—second President of the National Academy of Sciences. From 2013 to 2016 she was Editor-in-Chief of *Science* journal. She was Director of the U.S. Geological Survey (USGS) from 2009 to 2013, during which time USGS responded to a number of major disasters, including the Deepwater Horizon oil spill. For her work to help contain that spill, she was awarded the U.S. Coast Guard's Meritorious Service Medal.

She is a Fellow of the American Geophysics Union (AGU), the Geological Society of America, the American Association of the Advancement of Science, and the International Association of Geodesy. Ms. McNutt is a member of the American Physiological Society, and the American Academy of Arts and Sciences, and a foreign member of the Royal Society of the U.K., and the Russian Academy of Sciences. In 1998 she was awarded the AGU's Macelwane—Macelwane Medal for research accomplishments by a young scientist, and she received the Maurice Ewing Medal in 2007 for her contributions to deep sea exploration. Thank you for being here.

Following Ms. McNutt, Mr. Patrick Gallagher. As the University of Pittsburgh's 18th Chancellor, Mr. Gallagher directs one of the Nation's premiere public institutions of higher education and research. In this role, he oversees a community on the move of more than 34,000 students at five distinct campuses. He also supports the work of more than 13,000 faculty and staff members, who are committed to advancing the University's legacy of academic excellence, community service, and research innovation. Under his leadership, Pitt has strengthened its status as one of the Nation's premiere public institutions for higher education and research, including being named the top public university in the Northeast by *The Wall Street Journal* and *Time's Higher Education*.

Prior to his installation at Pitt, Mr. Gallagher spent more than 2 decades in public service. In 2009 President Barack Obama appointed him to direct the National Institute of Standards and Technology (NIST). While in this role, he also served as Acting Deputy Secretary of Commerce before leaving for Pitt in the summer of 2014. Today he serves as the Chair of Internet2, and is active as a member of boards and forums, including the NCAA Division I President Forum and the Allegheny Conference of Community Development. He also completed terms of a wide range of community boards and committees, including President Obama's 12-person Commission on Enhancing National Cybersecurity in 2016. He holds a PhD in Physics from Pitt—it's Pitt, Pitt, Pitt, isn't it? And a Bachelor's Degree—I'm just jealous. I'm from Texas. A Bachelor's Degree in Physics and Philosophy from Benedictine College in Kansas. Thank you.

Mr. Mehmood—Dr. Mehmood Khan, the Vice Chair and Chief Scientific Officer of PepsiCo. He is PepsiCo's Vice Chair and Chief Scientific Officer, head of global R&D. PepsiCo's businesses make hundreds of foods and beverages that are respected names globally. Prior to joining PepsiCo, Dr. Khan was President of the Takeda

Global Research and Development Center, overseeing Takeda Pharmaceuticals Company's worldwide R&D efforts. Previously, he was an attending—he was attending staff endocrinologist at Mayo Clinic and Mayo Medical School in Rochester, Minnesota, serving as director of diabetes, endocrine trials unit.

Dr. Khan has been recognized by academic and international organizations, including honorary doctorate degrees, the Ellis Island Medal of Honor, Career Achievement Award, and Pinnacle Award, and is an elected fellow of the Royal College of Physicians in London. He serves as Chair of both the U.S.-Pakistan Business Council, and the U.S. Council of Competitiveness in Washington, D.C., and is a member of the board of FFAR, U.S. Department of Agriculture, and the Visiting Committee for Advanced Technology at the National Institute of Standards and Technology. He also serves as judge for the Lemelson Innovation Prize at the Massachusetts Institute of Technology. Thank you for being here.

We will begin with our first witness, Dr. McNutt.

TESTIMONY OF DR. MARCIA MCNUTT, PRESIDENT OF THE NATIONAL ACADEMY OF SCIENCES

Dr. MCNUTT. Well, Chairwoman Johnson, and Members of this distinguished Committee, thank you for the opportunity to testify today. As you've heard, I'm Marcia McNutt, President of the National Academy of Sciences, an organization that was chartered by Abraham Lincoln as non-partisan advisors to the Nation. I'd like to discuss what I believe is one of the most important issues facing our Nation, the health of the U.S. innovation enterprise, and the implications for our long-term global competitiveness.

Allow me to begin with the following question. How do we gauge the competitiveness of American science and technology on an international scale? So it's true that the U.S. is the world leader in Nobel Prizes. We also lead in creating new industries from science discoveries, and in translating basic science into novel medical therapies that improve our lives, but these are all lagging measures of our competitiveness. An operator of a manufacturing plant would not wait until products stop coming off the assembly line to realize that she needs to order more raw materials. In the same way, the U.S. cannot afford to wait for a decline in top international awards, or until our high-tech industries stagnate to realize that we've already lost our edge.

So then, what are the leading measures of our competitiveness that we should be tracking, and how are we doing in those leading measures? The first measure is investment in research and development. Well, thanks to the farsightedness of this Committee, and Congress in general, the U.S. is doing OK, but I'm concerned. You've already heard that China's catching up, and may surpass us, and with the sequestration caps, we could fall behind. And there is nothing more disruptive to the U.S. science enterprise than huge swings in science budgets. That could be crippling to us. Therefore, we can't stop now in continuing our investment.

Also, when I ask people from all perspectives, whether it's young researchers, established researchers, or industry consumers of government-funded science, where we are underinvesting, they say it's in high-risk, high-reward research. Too many of the Federal funding programs have become overly conservative, such that only incremental research that looks like a sure bet can get funded. This is not the sort of research that leads to the breakthroughs that fuels tomorrow's new industries.

A second indicator of our competitiveness in science and technology is the extent to which the world's most brilliant young researchers seek to train and work in the U.S. research enterprise. Without a doubt, we are in a global competition for the best talent. What has put the U.S. on top in science and technology is that for decades the world's best and brightest have flocked to our universities to be educated, and the most capable of these have stayed in it to enrich our enterprise. So the question is, is that still the case today? The answer is, sadly, no. Applications for graduate school in science and engineering departments nationwide from abroad are in the decline. There is a strong perception, if not the reality, that international students are not welcome here.

On top of that, international students, even if we train them here, are now being lured back home by excellent jobs, first-class equipment, and better funding. While we should still try to attract the most promising young scientists, no matter what their national origin, and work to keep them here, if they are the best, we should resign ourselves to the fact that we will no longer have the same supply of talent from overseas. I agree completely with Chairwoman Johnson that we have to draw upon the full human resources we have here at home. It used to be that science was a white male occupation. Thanks to concerted effort, now a significant faction of excellent women scientists populate the ranks in many science departments. Unfortunately, science still fails to attract minorities to the field. We cannot meet our need for top scientists if we do not aggressively attract a workforce that reflects the full diverse talent of America.

While the U.S. needs to remain the top competitor, at the same time, I believe strongly in scientific cooperation. There exists a certain scale of science that transcends the ability of a single nation to invest sufficiently to solve problems at the cutting edge. All problems benefit from such cooperation, but no one lines up to cooperate with the B team. If we lose our edge as the A team, opportunities for international cooperation will suffer as well. The U.S. has already ceded leadership in a number of areas. Why would we cede leadership in science? It benefits our quality of life, and it feeds our innovation machine. We can keep our edge if we invest in high-risk, high-reward research, attract a more diverse scientific workforce, and keep our doors open to international talent. Thank you.

[The prepared statement of Dr. McNutt follows:]

"Maintaining U.S. Leadership in Science and Technology"

Statement of

Marcia K. McNutt
President, National Academy of Sciences
National Academies of Sciences, Engineering, and Medicine

before the

Committee on Science, Space, and Technology
U.S. House of Representatives

March 6, 2019

Chairwoman Johnson, Ranking Member Lucas and members of the Committee, thank you for the opportunity to testify today. I am Marcia McNutt, president of the National Academy of Sciences. I am pleased to be here on behalf of the National Academies of Sciences, Engineering, and Medicine to discuss what I believe is one of the most important issues facing our nation — the health of the U.S. innovation enterprise and the implications for our long-term global competitiveness.

I will begin by providing a brief overview of the National Academies of Sciences, Engineering, and Medicine. We work on a remarkable range of issues that have science and evidence at their core, and we have long been a valuable resource for policymakers and the public.

More than 150 years ago, the National Academy of Sciences was created through a congressional charter signed by Abraham Lincoln to serve as an independent, authoritative body outside the government that could advise the nation on matters pertaining to science and technology. Under that original charter, the National Academy of Engineering (NAE) was founded in 1964 and the National Academy of Medicine (NAM, formerly the Institute of Medicine, IOM) in 1970.

Every year, approximately 6,000 Academies members and volunteers serve pro bono on our consensus study committees or convening activities. Our consensus study process is considered the gold standard of independent, nonpartisan, evidence-based advice. We do not advocate for specific policy positions. Rather, we enlist the best available expertise across disciplines to examine the evidence, reach consensus, and identify a path forward on some of society's most pressing challenges. In recognition of the fast-changing policy environment in which we all operate, we recently launched an Academies-wide effort to transform our processes, to ensure that our work is even more timely and relevant, without sacrificing the rigor and objectivity you rely upon.

Over the years, our advice informed the formation of the U.S. national park system and national highway system, the launch of the U.S.'s first Earth-orbiting satellite, and the mass-production of penicillin and other lifesaving drugs. More recently, our work strengthened the scientific consensus and public understanding of climate change, provided the blueprint for the Human Genome Project and precision medicine, bolstered the forensic science that underpins the U.S. criminal justice system, and provided a comprehensive estimate of the economic impacts of immigration into the U.S.

In 2018 alone, our advice covered issues as varied as modernizing the nation's interstate highways, securing the U.S. voting system, assessing the future of quantum computing, identifying the health effects of e-cigarettes, and eliminating lung diseases caused by exposure to coal mine dust. We proposed feasible paths for space exploration and the search for life in our universe, laid out a decadal strategy to enhance space-based observations of Earth and its complex systems, proposed measures to make prescription drugs more affordable, provided a research agenda for promising net emission technologies that remove carbon dioxide from the air, and recommended actions for fostering more openness and transparency in the research process. We also characterized the profound damage caused by sexual harassment — not only to the careers, health, and well-being of women who are harassed but also to the entire research enterprise. I am proud that our report helped this committee to take action on this front.

This year promises to be just as productive for the National Academies, and on issues such as modernizing the U.S. electric grid, defining the importance of reproducibility in research, helping public transportation adjust to disrupters such as Uber and Lyft, outlining the role of social and behavioral sciences in national security, and developing a blueprint for governance and research of climate engineering strategies. And our work extends far beyond our consensus studies; for example, our new Environmental Health Matters Initiative brings together expertise across the Academies to explore the science about environmental factors and human health, and our new Climate Communications Initiative provides policymakers with an unbiased resource for evaluating the science around global climate change. I invite you to review the attached list of 2018 reports specifically relevant to this Committee's jurisdiction.

Many of our studies originate in legislation; in the last Congress, for example, roughly 240 bills and resolutions were introduced either requiring a new Academies study or citing our previous work, and 26 new studies were ultimately mandated by law. During the 115th Congress alone, our members, volunteer experts, and staff participated in close to 200 congressional briefings. We are grateful that, for a non-governmental entity, this kind of presence on Capitol Hill may be unmatched. It reflects the incredible breadth of policy-relevant domains our vast network of experts can tackle, as well as the indispensable role that scientific inquiry and evidence can play in everyday life, beyond what one might consider to be conventional "science policy" issues.

A Strong U.S. Research Enterprise

Our work at the National Academies often centers on ensuring that advances in scientific knowledge, biomedical research, and technology are employed responsibly, and for the benefit of the nation. However, for those advances to occur in the first place, there must be strong and sustained investments in the people, facilities, and infrastructure that comprise our nation's innovation enterprise. Without this support, our nation will lose its competitive advantage in the global marketplace as the world's top talent will take their talent and ideas elsewhere, and the economic growth they have long generated here in the U.S. will follow. To be clear, this is not about creating jobs for scientists: this is an existential threat to America's greatness and the long-term welfare of our people.

More than 15 years ago, the National Academies released a landmark report called *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future*, which stressed the importance of research for enhancing American competitiveness in a global economy. The report was instrumental to the development and adoption of the America COMPETES Act, the effort to increase basic research funding, and the creation of the Advanced Research Project Agency (ARPA-E) at the U.S. Department of Energy.

Now, in 2019, the messages from that report resonate more than ever. In an increasingly complex global economy, we simply cannot afford to let U.S. leadership in science slip away. In some cases, it already has. Given the often long lag time from research to applications, we may not realize the impacts of being behind until we are far behind, watching other nations reap the economic rewards and strategic advantages of early S&T investment.

The number of research journal publications by country is one metric to assess the vitality of U.S. research. It reflects a country's research capabilities and ability to generate new knowledge, as well as the potential pathways for that knowledge to technology innovation. According to the National Science Board's most recent Science and Engineering Indicators, the total number of

U.S. articles published began declining around 2014, despite consistent, steady growth in previous decades. At the same time, articles by Chinese researchers continued to increase significantly, ultimately surpassing the U.S. in 2016. This does vary considerably by field; the U.S. and European Union (EU) are still leading in publishing biomedical science articles, and China produces the most engineering articles.

Another measure is the relative output in knowledge- and technology-intensive industries. In the medium-high technology manufacturing fields such as vehicle parts, chemicals, and electrical equipment, China's output surpassed the U.S. in 2008 and the EU in 2011. But perhaps more concerning, in the high-technology industries such as aviation and telecom — where the U.S. has held a clear lead in the past — China is quickly gaining ground because of its substantial investments in research and advanced manufacturing, even as our and other nations' investments have leveled out.

These two metrics are good reminders of how innovation occurs across a spectrum — from knowledge generation through early stage basic research, to applied research and technology development, to deployment or commercial application. And at every step, we are facing increasingly intense competition from other countries, some of which may have more nimble and unconstrained innovation systems.

The U.S. research enterprise has traditionally been supported by a combination of government, university, private foundation and, of course, industry support. For the last few decades, private sector funding of research has indeed comprised an increasingly larger share of total R&D. But, by definition, industrial R&D is focused largely on near-term, more incremental improvements to existing commercial products and systems. In contrast, federally funded research generally generates crucial foundational knowledge for broader societal benefit, in ways that industry cannot or will not do alone. It is worth noting that those functions are not definitive and the process is not necessarily linear. Industry can certainly sponsor basic research, and federal funding can play an indispensable role in some later-stage technology innovation where the societal benefit is clear.

Federally funded research still comprises roughly a quarter of total R&D expenditures in the U.S. With so many competing demands on the federal budget, some question whether research still deserves high levels of continued support. Given the proven return on investment in publicly sponsored research and its role in generating and sustaining the STEM workforce, there can be no doubt: America is clearly served better through robust federal support of our research enterprise.

The STEM Talent Pipeline

Economic prosperity, national security, and advances in public health in the U.S. have for generations depended on a strong and diverse STEM talent pipeline. For decades, the world's top students flocked to U.S. universities to be educated, and the most capable of those have remained here to enrich our research enterprise and economy. Likewise, we did not have to worry about keeping our own domestic talent in the U.S. At one time we held a clear advantage because other countries lacked the resources or motivation to compete with the U.S. That is certainly not the case in 2019. We are in a global race to generate here and attract from abroad the best and brightest, who are looking for stable funding, better facilities, and the promise of lucrative careers.

There are troubling signs that the U.S. research workforce is getting older, U.S.-born students are not entering STEM fields in sufficient numbers, and foreign STEM students are no longer coming to the U.S. and staying to build lives and contribute to the economy as they did before.

The U.S. can maintain its competitive edge if we fix the incentives to improve career paths, attract a more diverse domestic scientific workforce, and keep our doors open to international talent.

Regardless of their country of origin, STEM graduates must see a successful future in their field if we hope to retain them. But far too often, they are discouraged by the high costs of education, decreasing success rates of grant proposals, and the long training phases of their careers. In our 2018 report *The Next Generation of Biomedical and Behavioral Sciences Researchers*, we note:

- The average age of first receipt of a NIH grant, the R01, has risen from 36 years old in 1980 to 43 years old in 2016.
- The share of biomedical Ph.D. recipients able to secure a tenure-track academic research position within six years has fallen from 55 percent in 1973 to 18 percent in 2009.
- The proportion of NIH research project grant dollars awarded to investigators under age 50 has declined from 54 percent in 1998 to 39 percent in 2014.
- While less than half of the current biomedical postdoc population are U.S. citizens, very few NIH postdoctoral and early career awards are available to non-U.S. citizens.

Furthermore, as identified in our 2018 report *Graduate STEM Education for the 21st Century*, the deeply technical graduate education system often does not adequately prepare students with a broad combination of the core competencies needed to lead in the modern workforce.

The cultural diversity of a nation's workforce is a key factor in its ability to innovate and compete in a global economy. We need to look beyond the traditional research universities in cultivating the pipeline of STEM talent, and the research community should better reflect the nation as a whole. One of our most recent reports, *Minority Serving Institutions: America's Underutilized Resource for Strengthening the STEM Workforce*, notes that the nation is still falling far short in attracting and retaining students of color to STEM fields. With over 700 MSIs in the U.S., and an ever-expanding range of STEM-related fields, this is talent that we obviously cannot afford to squander. I invite you to review these reports for a comprehensive look at the issues and lists of actions all stakeholders can take to improve the system.

Any discussion about U.S. S&T leadership must acknowledge the critical role that non-U.S. students and workers have to play in our competitiveness. Though U.S. universities remain the destination of choice for international talent, for the first time the numbers have fallen in recent years. According to the last Science and Engineering Indicators, international science and engineering graduate student enrollments dropped 6 percent from 2016 to 2017. Though this is a recent phenomenon, the indications are that the trend may continue. The most recent data from the Council on Graduate Schools indicate a continued decline in temporary visa holder enrollment in 2018. The trends vary across fields, with some of the sharpest drops in engineering and physical and earth sciences. For example, according to a recent survey by the American Physical Society, international applications to U.S. physics Ph.D. programs declined an average of 12 percent in 2018. At the same time, our competitor institutions in Canada, Germany, Australia, and elsewhere saw significant increases. Unfortunately, this comes at a time when both funding for U.S. public universities and entry of U.S-born students into STEM fields have fallen.

Our report *Graduate STEM Education for the 21st Century* states that foreign graduate students who remain here after earning their degrees benefit the U.S. in myriad ways, including contributing to an increase of more than $39 billion to our economy in 2016. Stay rates are highest in fields where temporary visa holders are most prevalent: engineering, physical sciences, and life sciences.

We must also recognize the ever-shifting landscape of risks and the fact that our competitors will continually seek to exploit our open academic research system for their strategic security and economic advantages. Healthy vigilance in this regard will require the close coordination of our national security, law enforcement, and research funding agencies, as well as academic and other research performing institutions, to ensure that we do not underestimate the risks or undermine the deep benefits foreign students and international cooperation provide for our nation. With foreign students making up roughly one-third of science and engineering graduate students in the U.S. — and the clear majority in some S&T fields — we must very carefully consider the long-term impacts of policy measures that discourage or ban non-U.S. citizens from contributing to our innovation system.

International Cooperation

Across a range of S&T domains, international competition is intense, and with our allies and adversaries alike. Fortunately, the global scientific community has a long tradition of transcending political and economic differences to coordinate or consult on major scientific challenges for the health and welfare of the world, and to push the frontiers of knowledge beyond what one country can do on its own. Examples today can be seen in the International Space Station, the ITER nuclear fusion reactor, the Large Hadron Collider at CERN, Arctic and Antarctic research, and nonproliferation of nuclear weapons. International coordination may well play a critical role in emerging and highly competitive fields with broad societal impacts, such as artificial intelligence, quantum computing, robotics, synthetic biology, nanotechnology, and even lunar exploration.

Fostering these exchanges is more important than ever. Science and engineering are increasingly international endeavors, and are being rapidly transformed by globalization, interdisciplinary team-driven research, and information technology. International collaboration and cooperation are also important for informing the responsible conduct of science, avoiding and identifying fraud and bias, and communicating findings with the public. This is especially critical for fast-moving, cutting-edge areas of research that have global implications. For instance, Human genome editing offers great promise around the world in treating genetic diseases, but it is imperative that we examine the many scientific, ethical, and governance issues raised by powerful new genome editing tools such as CRISPR-Cas9. Of particular concern are heritable genome edits that might be passed down to future generations.

The National Academy of Sciences and the National Academy of Medicine have organized two international summits and a consensus study to explore the complex issues surrounding human genome editing. The Second International Summit on Human Genome Editing — co-hosted last year with the Academy of Sciences of Hong Kong and the Royal Society of the U.K. — brought together in Hong Kong more than 500 researchers, ethicists, clinicians, patient groups, and others from around the world to discuss the issues, and was viewed online in approximately 190 nations

The summit was already generating international headlines when a Chinese researcher — in violation of long established scientific principles and norms — claimed to have edited early embryos that resulted in the birth of twins. The news drew widespread condemnation, but it also served to heighten the urgency for more in-depth analysis of the complex scientific, ethical, and societal issues that surround heritable genome editing. This year, the NAS and NAM are partnering with the Royal Society and other academies around the world to form an international commission tasked with developing stringent criteria and standards to guide responsible decisions about heritable human genome editing research and applications.

Scientific cooperation is just as important as competition if we hope to address large-scale global issues such as human genome editing. However, if the U.S. loses its edge in science and technology, opportunities for international collaboration will also suffer.

Conclusion

As we have for more than 150 years, the National Academies stand ready to serve the nation and the world on these and many other issues. We can provide a science and evidence base as you assess the appropriate functions of agencies and programs, set priorities for research funding, and deliberate on how to strike the right balance between public and private contributions. We can provide guidance for decisions about making the most of federal investments in the research enterprise, including the STEM talent pipeline, facilities, and infrastructure. However, we must all keep in mind that other nations are not hesitating to debate many of the issues we face. They are examining every metric of competitiveness, and looking years ahead to make large investments in their own expanding research enterprise.

Yes, the U.S. has ceded leadership in some areas, but we remain at the top in many others. As Members of the U.S. House Committee on Science, Space, and Technology, you have the opportunity to make policies and conduct oversight that ensures we do not ever surrender our global leadership in science and technology. The stakes are simply too high for U.S. economic competitiveness, national security, and the health and well-being of our citizens. Together, we must support and maintain a strong, robust U.S. research enterprise.

Additional Resources (with links)

- National Science Board – *Science and Engineering Indicators 2018*
- NASEM Study - *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future* (2007)
- NASEM Study - *The Next Generation of Biomedical and Behavioral Sciences Researchers: Breaking Through* (2018)
- NASEM Study - *Graduate STEM Education for the 21st Century* (2018)
- NASEM Study - *Minority Serving Institutions: America's Underutilized Resource for Strengthening the STEM Workforce* (2019)
- Council of Graduate Schools – *International Graduate Applications and Enrollment: Fall 2018*
- American Physical Society – *International Applicants Survey Results* (2018)
- The Interacademy Partnership – *Doing Global Science: A Guide to Responsible Conduct in the Global Research Enterprise* (2016)
- NASEM Initiative – *Human Genome Editing*

NATIONAL ACADEMY OF SCIENCES

MARCIA McNUTT
PRESIDENT, NATIONAL ACADEMY OF SCIENCES

Marcia McNutt (B.A. in physics, Colorado College; Ph.D. in Earth sciences, Scripps Institution of Oceanography) is a geophysicist and the 22nd president of the National Academy of Sciences. From 2013 to 2016, she was editor-in-chief of *Science* journals. McNutt was director of the U.S. Geological Survey from 2009 to 2013, during which time USGS responded to a number of major disasters, including the Deepwater Horizon oil spill. For her work to help contain that spill, McNutt was awarded the U.S. Coast Guard's Meritorious Service Medal. She is a fellow of the American Geophysical Union (AGU), Geological Society of America, the American Association for the Advancement of Science, and the International Association of Geodesy. McNutt is a member of the American Philosophical Society and the American Academy of Arts and Sciences, and a Foreign Member of the Royal Society, UK, and the Russian Academy of Sciences. In 1998, McNutt was awarded the AGU's Macelwane Medal for research accomplishments by a young scientist, and she received the Maurice Ewing Medal in 2007 for her contributions to deep-sea exploration.

Chairwoman JOHNSON. Now Dr. Gallagher.

TESTIMONY OF DR. PATRICK GALLAGHER, CHANCELLOR OF THE UNIVERSITY OF PITTSBURGH

Dr. GALLAGHER. Thank you. Chairwoman, and Ranking Member Lucas, and all the Members of the Committee, you know, after being in front of this Committee regularly for many years, it's a distinct pleasure to be back before you today to talk on this important topic of Maintaining U.S. Leadership in Science and Technology. As investments, the investments we make in science and technology are among the highest payback investments that any nation can make. And, in fact, the United States owes much of its current economic leadership, military superiority, high standard of living, health and safety for our citizens, energy security, and our dominant geopolitical leadership position to these S&T investments. By any measure, the return on investment has been remarkable.

But the United States faces a dramatically different global S&T enterprise now. Instead of standing alone, other nations have recognized the importance of R&D to their industrial competitiveness, and so any assessment of U.S. leadership must be a comparison of the U.S. S&T enterprise against this changing global enterprise. And the rapid growth of science and technology in these other countries should cause us to re-evaluate and re-examine our approach.

More than anything else, our S&T success is built on talent, so leadership must be assessed by the quantity, the quality, and the usefulness of that talent to our national needs. We must face these international competitive pressures first by remaining an attractive location for worldwide talent. America's university system is immensely capable, which is why the United States has been the destination of choice for the best and brightest international students for decades. But now our competitors are making a concerted effort to attract these same students, and they are beginning to succeed.

UNESCO (United Nations Educational, Scientific and Cultural Organization) data show that the share of the world's internationally mobile students enrolled in the United States fell by 25 percent between 2000 and 2014. Our universities must remain welcoming, engaging, and respectful of higher—of international students, employees, and visitors regardless of their country of origin. Indeed, our competitiveness depends on it. Global leadership in S&T is as essential to U.S. interests as it has been in the past, but we need to examine whether some of our long-held assumptions remain valid in this air of increasing global competition.

First, you know, training the next generation of scientists and engineers is an essential goal of R and—Federal R&D policy. In fact, I would say, arguably, no other investment has a larger effect on the ultimate size, quality, and composition of the U.S. talent in the United States. But training PhDs and post-docs is incredibly expensive, and, so far, unavoidably time intensive. In the past, we made these decisions based on our own needs, and not on the context of what others were doing around us, and we have not yet found ways to link industry's workforce needs effectively and efficiently to the rate at which Federal R&D investments can or should change. If—failing to do this, we risk severe oversupplier shortages in science and technology workforce.

Second, we need to develop more effective ways to reconcile our government's appropriate goal of supporting U.S. economic competitiveness with a largely segmented R&D enterprise. A wide and growing—the—two issues jump out in this space. There is a wide and growing gap between the public sector-funded and university led world of basic research with the private sector-funded and industry-led R&D space there. Indeed, many of the largest R&D performers in industry are now multinational companies, with a footprint in multiple countries, so they benefit from the S&T investments around the world.

And, finally, we can no longer assume a hegemonic American dominance of global R&D. The two most populous countries in the world, China and India, are making enormous strides in their development, and this is no accident. They maintain deliberate and sustained strategies to mimic U.S. S&T policy, and they are now reaching a scale comparable to ours. Both are becoming much more economically and technically competitive, and they will remain so. For this reason, we need to have a better collective understanding and situational awareness of the global R&D sector. Other countries are very systematic in their efforts to collect, translate, and analyze our science policy documents, in fact, much more so than we are of theirs. That is a shortcoming that should be corrected.

In the future, even the United States will not be able to afford leading every science and technical field, so we will need to be more sophisticated in identifying those areas where the U.S. must have the leadership position, and where a position of parity with the research capacity of our competitors, or even a posture of careful watching, can be maintained. So, Madam Chairwoman and Members of the Committee, I would once again like to thank you for the opportunity to appear before you this afternoon, and I look forward to you—as you tackle these important issues, and I'm looking forward to your questions. Thank you.

[The prepared statement of Dr. Gallagher follows:]

Statement by the Honorable Patrick D. Gallagher
Chancellor, University of Pittsburgh

before the

United States House Committee on Science, Space, and Technology's Hearing on "Maintaining US Leadership in Science and Technology"

March 6, 2019

I would like to begin by thanking Chairwoman Johnson, Ranking Member Lucas, and all the members of the House Committee on Science, Space, and Technology for the invitation to speak today. I have many fond memories of testifying before, and working with, the members and staff of this Committee over my 21-year government career. Through that experience I grew to appreciate the unique and vital role that this committee plays in our nation's science and technology enterprise, and it is with that fond appreciation that I tell you what a real pleasure it is to be back before you today to discuss the topic of U.S. leadership in science and technology.

Assessing U.S. S&T leadership

The charge from the Committee to today's witnesses was a broad one: to assess the current state of U.S. science and technology in the context of today's competitive and rapidly changing global environment and to identify potential elements of our national policy that are vital to maintaining U.S. leadership. From my own personal background, including my various roles in the U.S. science and technology enterprise, I can fully appreciate the scope and complexity of what you have asked us to address. To be helpful to your task, I would like to make a few general observations and then focus my remarks on an examination of the nation's science and technology enterprise from the specific perspective of one of its many elements: namely, research-intensive universities in the United States. Specifically, my perspective and examples will be from the University of Pittsburgh, where I currently serve as chancellor.

The nation's science and technology (S&T) enterprise is massive and complex, but in its modern form is a relatively recent construct, achieving much of its current scale and composition over the period beginning after the end of World War II. According to NSF's National Center for Science and Engineering Statistics, the federal government has spent approximately $5 trillion (constant 2009 dollars) on R&D activities since 1953. This sizeable public investment has been complimented by an even larger investment by the private sector in the United Sates, an investment concentrated in R&D intensive industries and firms. Collectively, this is one of the largest investments that any one nation has made in science and the related technologies, and the impact has been transformative for our country and for global society. Without exaggeration, the United States today owes much of its current economic leadership, military superiority, high standard of living, health and safety infrastructure for our citizens, energy security, and our dominant geopolitical leadership position to these S&T investments. By any measure, the "ROI" has been remarkable.

The Committee charged us to evaluate U.S. leadership in science and technology. The use of a competitive measure of performance – leadership – deserves a quick comment, since it infers that there is a policy benefit to "being a leader" beyond trivial benefits, like national bragging rights. If we assume that the government's primary goals are to protect and defend the country and to promote our national well-being, then the inference is that being in a leadership position in S&T relative to other countries must advance these primary objectives. One simple way to break this down is to consider our federal S&T investments as having two outcomes: to create knowledge (i.e. scientific understanding and data) and to create capability (i.e. the trained scientists and engineers – and the tools – that create that knowledge). Leadership then can be defined from either outcome.

Leadership in scientific or technology knowledge can be assessed according to the quantity, quality or usefulness of that knowledge. Is our stock of knowledge greater than that of other countries? Do we have better data and greater knowledge than our competitors or that they don't possess? Is our S&T knowledge having demonstrable impact on advancing our most important national needs, creating new economic activity, or enhancing our competitiveness?

Leadership in scientific capability can be assessed by the relative abilities of our scientific facilities or assets, but the most important measure is the quality and quantity of our scientific and technical workforce. Specifically, leadership is assessed by our ability to compete globally for talent. Are we better in developing the highest quality new talent than is our competition? Is the size and composition of our scientific and engineering workforce responsive to our national needs and to the demand by American industry for a highly skilled workforce? Finally, leadership can be assessed by the productivity of our S&T workforce. Do technical communities in the U.S. lead in the creation of new knowledge? Do we have faculty who are making the most significant discoveries or developing the foundational technologies in their fields?

Assessing S&T leadership at U.S. research-intensive universities

Universities, especially research-intensive universities, play a unique role in this S&T "ecosystem." They are both producers of new scientific and technological knowledge, and they are the primary drivers for building our S&T capacity. Today by nearly every measure, and despite growing international competition, the best research-intensive U.S. universities remain global S&T leaders. Sixty percent of the top 50 universities in the world named in the five most respected international rankings of global universities were American. Among the top 20 universities world-wide, the US is even more dominant: 75 percent were American.

We can assess the U.S. leadership position by the behavior of countries competing with us. Many competing industrialized countries have explicit targets to grow their domestic S&T capability to rival or challenge U.S. leadership. Examples of research universities in other countries openly modelled after the top U.S. universities are easily found. The King Abdullah University of Science & Technology in Saudi Arabia was consciously modeled after CalTech. Others were created through direct partnerships with U.S. universities; New York University Abu Dhabi is one example. Others are established directly by U.S. universities; SUNY Korea is an example. Further evidence of our leadership is that U.S. graduates, particularly our foreign-born scholars, are targets of talent attraction programs, especially those of technology-intensive middle-income countries.

At Pitt, our own accomplishments mirror this national picture. Following the growth of research funding, especially in the health sciences since the mid 1990's, Pitt has grown to be a top 20 research-intensive university as measured by the share of federal R&D dollars. (This position rises to top 5, when considering only NIH funded research.) Our success has allowed the university to assemble a world-class faculty, who compete successfully for federal funds enabling them to make the discoveries that drive their disciplines.

Just one example of the importance of recruiting world-class faculty is the important partnership between Pitt and three world-renowned French research institutions; the University Pierre et Marie Curie of the Sorbonne Universités in Paris, the Institut National de la Santé et de la Recherche Médicale (Inserm); and the Centre National de la Recherche Scientifique (CNRS), to focus on collaborative research and education in the fields of medicine and biomedical sciences.

This partnership was formed after the recent recruitment of José-Alain Sahel, M.D., one of the world's top experts in retinal diseases, as the chair of the Department of Ophthalmology at Pitt's School of Medicine. The agreement will enable researchers of all four institutions to cooperate on fundamental research, development of novel therapeutics, and clinical trials, with an initial focus on ophthalmology, vision and neuroscience. We will exchange academic personnel, host joint academic conferences, and exchange of scientific, educational and scholarly materials.

As a measure of our impact, the University set new records last year for invention disclosures submitted, licenses and options, and startups formed. By nearly every measure, the culture of innovation and entrepreneurship at Pitt is blossoming. This year the University set new records with 363 invention disclosures submitted (nearly one for every day of the year), 162 licenses and options, and 23 startups formed. Pitt also rose in the rankings of worldwide university patent issuances to 21st, up from 35 in 2015 and 27 in 2016, according to the National Academy of Inventors and Intellectual Property Owners Association annual report. Our startup number increased by more than 50 percent over last year, placing Pitt in the top five individual universities nationally based on the most recent reported results.

Pitt's footprint on the region is immense, with nearly $4 billion of yearly economic impact, we generate over $190 million in local and state tax revenue, support just under 30,000 jobs throughout Pennsylvania, and produce over $74 million in charitable and volunteer service donations. The university role in shaping the region's economy is probably most dramatically shown with the Pittsburgh "renaissance" where, based on the deep expertise at Pitt and our neighbor Carnegie Mellon University, Pittsburgh was reshaped from a heavy-manufacturing based economy, to one based on "eds and meds." In fact, in terms of current employment, today more people are employed in Pittsburgh healthcare and health sciences sector than were employed at the peak of the steel economy.

Challenging the assumptions necessary to maintaining leadership

If the current position of the U.S. S&T enterprise is one of leadership, at least from the perspective of U.S. research universities, then it may be a surprise that there is growing worry and pessimism about the ability of the U.S. to maintain this position. The reason is that the U.S. faces a dramatically different global S&T enterprise as other nations recognize the importance of R&D to their industrial competitiveness.

Although the United States remains atop the list of the world's R&D-performing nations, our share of total global R&D has declined from 40% in 2000 to 28% in 2016.[1] We are now in an era where the U.S. finds itself a parity player rather than the dominant global R&D figure, but only for a short while longer. Although total U.S. R&D spending has been growing steadily for decades with only minor exceptions and now exceeds $500 billion per year, it is only a matter of time before the U.S. is neither the leading source of R&D funds nor the world's leading performer of R&D. Steady investment by the European Union and astounding growth in R&D by China means the Federal government and American industry cannot spend our way back to an historically dominant position.

In the face of the considerable complexity of this internationally competitive landscape, we should examine whether some of the long-standing assumptions in U.S. science policy may be invalid or that function as barriers in this new environment:

Building capacity: how much and in what areas? Federal funding decisions have a strong effect on the size and composition of the U.S. S&T enterprise. Most of the major changes in the size or shape of the U.S. S&T workforce arose from significant shifts in federal R&D support to meet national needs. Major examples include the Manhattan Project, the manned space program, armed services labs during the cold

[1] John F. Sargent Jr., Global Research and Development Expenditures: Fact Sheet, Congressional Research Service (R44283, version 9), updated June 27, 2018.

war, the Strategic Defense Initiative, energy security and the development of the energy labs, the war on cancer, the doubling of NIH, etc. These "moonshot" efforts coupled clear national policy objectives to major shifts in the amount or composition of federal S&T funding.

Pitt is a good example. Leveraging strong programs in clinical medicine, the University began a concerted effort to strengthen its biology and health science programs during a period that coincided with the rapid growth of NIH funding. No major U.S. university rose faster or farther in scale and reputation in these specific areas of research, and the resulting impact on Pitt and the entire western Pennsylvania area has been transformative.

However, these types of targeted growth create problems as the S&T enterprise matures. Federal grant dollars to universities don't just fund the creation of new S&T knowledge, they also produce new scientists and engineers and create more demand. This is often negatively characterized as simply a form of entitlement behavior, but it has a very specific origin. When new and growing research dollars are targeted to grow a certain area, then new scientists and engineers are produced through the expanded graduate programs. A portion of these newly trained scientists then start their own laboratories and seek federal grant dollars. If future funding does not keep up with this form of growth then the entire S&T enterprise suffers from over competition (low success rates, risk adverse awards, depressed salaries, low employment). The long time and high cost of producing new scientists and engineers means that the university-funded enterprise is unstable against funding that doesn't match the growth. This is the origin of the perpetual call for more funding (over inflation) in all established areas of research.

This tension between stimulating growth and managing it are well known, but current federal S&T policy is not good at defining or signaling the amount of growth desired. Past attempts to link federal R&D expenditures to addressing expected capacity needs (or shortfalls) in the private sector have been unsuccessful, sometimes wildly so, as in the case of the incorrect predictions in the 1980s of looming shortages of Ph.D. scientists and engineers.[2] Lack of a stable, long range budget planning process means that this is a balancing act addressed in the annual budget process in decisions on how much money is made available in a particular area. However, there are recent efforts to explore reshaping federal grants to change the number of new scientists and engineers that are produced under federal grants.[3]

Private sector vs. public sector: a growing divide. Early U.S. science policy assumed a large role by large, research intensive industries. In fact, much of the early mobilization of the U.S. S&T enterprise during and after WW2 was achieved by leveraging the capabilities of these companies to address national needs. Early federal dollars made up a large part of the overall R&D expenditures for the country, but there was a significant level of participation in this research by industry and national laboratories operated by industry. As a result, this early S&T enterprise provided a close and collaborative relationship between industry performed or managed research with university-based researchers, particularly in the areas of fundamental scientific research funded by the government.

However, beginning in the 1980's with growing competition from other countries (particularly Japan), concerns began to grow that the United States was not fully realizing the economic benefits of its public investments in R&D. Key policy responses during this period included the Bayh-Dole Act to increase technology transfer from university-based research, the Stevenson-Wydler Technology Innovation Act to accelerate transfer from government laboratories, the R&E tax credit, and the creation of several technology programs to stimulate the amount of private sector R&D and the translation of federally-funded R&D knowledge to the commercial sector.

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[2] Greenberg, Daniel S. Science, money, and politics: Political triumph and ethical erosion. University of Chicago Press, 2001.

[3] Alberts, B., Kirschner, M. W., Tilghman, S., & Varmus, H. (2014). Rescuing US biomedical research from its systemic flaws. Proceedings of the National Academy of Sciences, 111(16), 5773-5777.

Over the past 30 years these investments have had a remarkable impact. Private sector R&D expenditures began to expand more rapidly than public sector spending. Today, private sector spending is nearly 3 times larger than the federal R&D budgets (the public sector R&D spending surpassed federal R&D spending in 1980). Similarly, U.S. universities began to expand their entrepreneurial activities by pursing commercialization of potential technology and licensing of university IP.

During this period of industrial R&D growth, the composition of industrial R&D also changed dramatically. Companies began to refocus their corporate R&D activities away from the areas of basic research that they had in common with university-based researchers, preferring instead to invest in late stage research and product development efforts. R&E tax credits succeeded in stimulating new investments by the private sector, but funding in areas that federal government funding actually shrunk. The landscape of industrial science labs common up until the late 1980's gave way to two separate, and distinct R&D worlds: one of university and national laboratory-based researchers working on federally funded R&D, and a separate infrastructure of industrial or contract research and development activities that had little or no connection with the universities. The "valley of death" actually got wider.

Today, by many measures the private sector, predominantly through research-intensive manufacturing companies, are a sizeable portion of the U.S. S&T enterprise. However, there is now much less interaction between the two domains. Interactions today occur when universities try to move into areas of industrially relevant work but are limited by constraints of managing industry sensitive information and conflicts of interest. There have also been efforts to pull industry towards the more open type of research favored at universities. This includes incentives towards industry consortia that work on areas of industrially important, but pre-competitive R&D. The recent manufacturing institutes were an example of this type of program.

Current federal policy is unclear in this environment. As a general rule, S&T knowledge is viewed as a "public good" (shared, openly disseminated, etc.) when it is fundamental scientific knowledge. However, it becomes a "private good" when S&T understanding is distilled into a useable commercial process or technology. The middle ground is poorly defined: what benefits a company by collaborating in the open scientific process, and what interests or financial considerations can a publicly funded scientist or engineer have if they collaborate in a potential commercial effort. The current segmented R&D environment means that public-private S&T partnerships must try to navigate this translation often in the face of these competing dynamics.

For universities these trends create a real problem. The largest industrial R&D performers tend to be large, multinational corporations with a global footprint. They are free to move their R&D activities to take advantage of the most favorable government-funded R&D capability anywhere in the world. Universities have tried to move towards commercially-important areas of research but get bogged down in questions of whether or not this is part of their mission and on how to manage the resulting conflicts. At a time when federal R&D prioritize focus on stimulating economic activity, there is a wide and growing gap between the public and private R&D worlds.

In Pittsburgh, a recent report by The Brookings Institution on the effect of the intersection of industry and university on the economic potential of western Pennsylvania noted an interesting problem. The two largest research universities in the region, Pitt and CMU, were effectively creating a "new economy" based on their respective strengths in areas of federal R&D support (mostly in health sciences and computer sciences and robotics, respectively). However, a similar measure of the patent portfolio of the region's R&D intensive companies (heavily weighted towards advanced materials) showed that was nearly no overlap with any research capacity within the universities. The result was two separate economies with little intersection, and a regional economy, that despite a very strong research capacity, that is underperforming in GDP and job growth. I don't imagine that we are alone in this situation, but all of us need to understand that factors contributing such a situation.

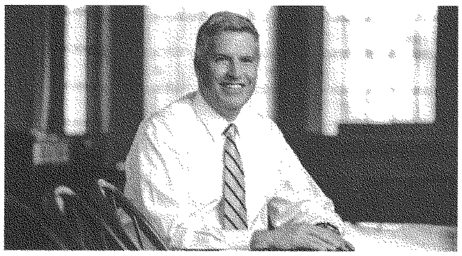
Facing the S&T future: growing global competition
As noted above, the U.S. faces a dramatically different global S&T enterprise as other nations recognize the importance of R&D to their industrial competitiveness. We must face these international competitive pressures by doubling down on remaining an attractive location for scientific and technical talent worldwide and by putting a premium on flexibility and speed in science policy innovation in the future

For decades, the United States has been the destination of choice for internationally mobile students. America's university system is immensely capable, but our international competitors are making a concerted effort to attract these students. UNESCO data shows the share of the world's internationally mobile students enrolled in the United States fell from 25% in 2000 to 19% in 2014. Our universities must remain welcoming, engaging, and respectful of international students, employees, and visitors regardless of their country of origin.

In this increasingly global R&D environment, U.S. universities need to prepare domestic STEM students with a broad set of skills necessary to lead in a high-tech, entrepreneurial international world. As an example, Pitt has established an International Research Internship Program, which includes study abroad opportunities for STEM students and brings students from leading global universities, such as Cambridge and the Kings College London, to Pitt for summer research internship experiences in our basic science and biomedical research labs. Pitt's PIRE:HYBRID research and education partnership with a number of top French universities in hybrid materials for quantum science and engineering is an example that formed from research collaborations.

More importantly, we need have a better collective understanding and situational awareness of the global R&D sector. Other countries have systematically collected, translated, and analyzed our science policy documents for decades. Korea, through their Korea Institute of S&T Evaluation and Planning, may be the among the best at doing this. We have done that solely through a national security lens, when we've done it, or not done it at all. The federal government needs to build the capacity to collect and analyze other countries strategic documents from a science policy perspective and feed that analysis into the research agencies and oversight bodies. In the future, we will need to be more sophisticated in identifying research areas where the U.S. must have a leadership position and those where a position of parity with the research capacity of our competitors or even a posture of careful watching developments elsewhere while maintaining a capacity to respond when necessary is acceptable.

Madam Chairwoman and members of the Committee, I would once again like to thank you for the opportunity to appear before you this afternoon. I look forward to working with you in the months ahead as you continue to craft policies that are vital to the health of the U.S. science and technology enterprise. I am happy to respond to any questions you may have.



Patrick Gallagher
Biographical Sketch

As the University of Pittsburgh's 18th chancellor, Patrick Gallagher directs one of the nation's premier public institutions for higher education and research. In this role, Gallagher oversees a community of more than 34,000 students at five distinct campuses. He also supports the work of more than 13,000 faculty and staff members who are committed to advancing the University's legacy of academic excellence, community service and research innovation.

Under his leadership, Pitt has strengthened its status as one of the nation's premier public institutions for higher education and research, including being named the top public university in the Northeast by *The Wall Street Journal* and *Times Higher Education.*

Prior to his installation at Pitt, Gallagher spent more than two decades in public service. In 2009, President Barack Obama appointed him to direct the National Institute of Standards and Technology. While in this role, Gallagher also served as acting deputy secretary of commerce before leaving for Pitt in the summer of 2014.

Today, Gallagher serves as the chair of Internet2 and is active on a number of boards and forums, including the NCAA Division I Presidential Forum and the Allegheny Conference on Community Development. He has also completed terms on a wide range of community boards and committees, including President Obama's 12-person Commission on Enhancing National Cybersecurity in 2016.

Gallagher holds a PhD in physics from Pitt and a bachelor's degree in physics and philosophy from Benedictine College in Kansas.

Chairwoman JOHNSON. Thank you, Dr. Gallagher. Dr. Khan?

TESTIMONY OF DR. MEHMOOD KHAN, VICE CHAIRMAN AND CHIEF SCIENTIFIC OFFICER AT PEPSICO

Dr. KHAN. Thank you, Chairwoman Johnson, and Members of the Committee. I am the Chairman of the U.S. Council on Competitiveness, and I just want to mention, as a council, we're nonpartisan members of an organization of 150 CEOs, university presidents, labor leaders, national laboratory directors, founded in 1986. We're dedicated to development of impactful policies and actions that boost U.S. productivity, drive inclusive prosperity for every American, and ensure the success of U.S. goods and services in the global marketplace. That context, and the fact—and I won't repeat what you've already heard, but I'll give an industry perspective. I've had the honor of leading R&D in three different industries, and starting my career as an academic in a lab that was funded by government research dollars, and I represent just about every scientist that you're going to find in industry in this country at some point will actually have their roots, and their training, at an academic institution or a national laboratory that was funded by the government.

So this is not a discussion about just supporting research in an academic setting, or research in a national laboratory setting, but ultimately, in the absence of that, we actually do not have a pipeline of scientists, and STEM graduates, and STEM trained individuals who will actually work in global companies, like mine at PepsiCo, and as I just announced this week, I'm retiring from my job at—as Vice Chairman of PepsiCo to take over as CEO of a startup biotechnology company in Cambridge, Massachusetts. And that amazing ecosystem, and several ecosystems around this country that are innovation hubs, rely on this pipeline of talent, and the thousands and tens of thousands of jobs that not only big companies create, but small startups, which are the primary engine of new job creation.

So what is different about the past versus today? You've heard about competitors. I won't repeat that, the fact that we are losing the lead in investment, but what I want to add to that and build on is the fact that the pace of change in science and technology has accelerated dramatically, even in my career over the last 30 years. Not only has it accelerated, but we are now seeing large disruptors. What do I mean by that? Well, let's take a look at what's happened, where we have traditionally led in—as U.S. technology with this digital revolution, which I would argue the U.S. ecosystem essentially created.

As a result of that, we're seeing vast deployment of sensors, the Internet of Things, artificial intelligence, biotechnology, gene editing, nanotechnology, autonomous systems, we all hear about this, but the fact is these are converging, and no longer individual disciplines, but when it comes to application into the real world, they actually are converging in their use, and being leveraged. And if we do not continue to develop the people who will use the next generation of these, we will not only have a workforce that's not trained, but a workforce that can't leverage the successes of this.

Unfortunately, as I look at it as a recent Member of the Oversight Committee at NIST, what really surprised me, in the early days of learning, is that more than half the facilities at NIST, on its two main campuses, are in poor to critical condition, and, unfortunately, that is reflected in many national laboratories around this—around the country. These were our—have been, and still in many ways are, the crown jewels of so much of the work that we've done in the past. We absolutely need to invest in them, because industry relies on those basic discoveries, for us to convert them. What I always coin is, we take the inventions from the academic and national laboratory system and make them into innovations. And that bridge, and that partnership of invention to innovation has been what's been driving not only the academic system, but our industry, and ultimately our commerce.

What are the options? And let me touch very briefly on—we can get into this in the discussion. As a council, we continue to recommend a number of steps. We Americans need to take many steps, including growing the number and diversity of STEM graduates, STEM educated workforce. You've heard that. We need to create greater opportunities for experiential learning, such as apprenticeships. Not everything needs a degree, and not everything needs a graduate degree. We need a workforce that is trained in STEM across the entire spectrum, but ultimately those will be developed and trained in the academic environment that we have, starting from kindergarten up to 12th grade, then college, and on to graduate school.

In conclusion, Americans are recognizing this. A number of surveys have shown that this is a high priority for our citizens. And, with this in mind, the Council has launched a National Commission on Innovation and Competitiveness Frontiers to double down on our efforts to optimize the Nation for this new unfolding innovation reality. I'm proud to serve as co-chair of this Committee, alongside Professor Michael Crow, President of Arizona State University, and over the next 3 years the commission is going to assemble top minds from industry, academia, labor, and the national laboratories to sharpen national, regional, and local leaders' understanding of this dramatically changing innovation ecosystem.

But I will leave you with one statistic which keeps me up at night the most, and that is, as a leader of a large industry R&D and small industry R&D, the average age of a science graduate working in industry, across all industries in the U.S. today, is already over the age of 50. While I have nothing personal against being over the age of 50, I can tell you that that means, within a decade, approximately half of our science-trained graduates in industry will be retirement eligible. We have no line of sight today on how to replace them. We need to figure out the policies, bipartisan, collectively, and ultimately, if my colleagues to my right do not have the resources to invest, I don't have the pipeline in the future to keep our companies running. Thank you, Ms. Chairwoman.

[The prepared statement of Dr. Khan follows:]

Testimony before the Congress of the United States House of Representatives
Committee on Science, Space and Technology

Dr. Mehmood Khan
Chairman, Council on Competitiveness and
Vice Chairman and Chief Scientific Officer, PepsiCo

March 6, 2019, 2:00 PM EST

Introduction

Thank you, Chairwoman Johnson, Ranking Member Lucas and members of the committee for inviting me to discuss the current state of U.S. science and technology and what it will take to maintain U.S. leadership.

My name is Dr. Mehmood Khan and I am the Chairman of the Council on Competitiveness, a non-partisan membership organization of 150 CEOs, university presidents, labor leaders and national laboratory directors. Founded in 1986, the Council is led today by the Honorable Deborah L. Wince-Smith who as President and CEO has led the development of impactful policies and actions that will boost U.S. productivity drive inclusive prosperity for every American and ensure the success of U.S. goods and services in the global marketplace.

I am honoured to serve on the Board of the Council with a tremendous group of leaders including industry vice chair, Mr. Brian Moynihan, the chairman of the board and CEO for Bank of America, our university vice chair Michael Crow, the president of Arizona State University, our labor vice chair, Mr. Lonnie Stephenson, international president of IBEW, and our Chair Emeritus, Mr. Sam Allen, CEO of Deere and Co.

This hearing comes at an important, possibly historic time for U.S. innovation.

Given the profound impact of science and technology on U.S. prosperity, standards of living, national security, modern society and geopolitical standing, every American should be concerned with the nation's ability to lead in science, technology and innovation.

More than any country in history, the United States has been the greatest driver and beneficiary of technology, innovation and a vibrant entrepreneurial spirit.

In the 19^{th} century, entrepreneurship and innovations surrounding agriculture, rail, oil, steel and electricity turned the United States into an industrial and economic powerhouse, laying the foundation for a manufacturing sector that provided middle class jobs and a higher standard of living for millions of Americans.

In the 20th century, American inventions and advancements in vehicle and aircraft technology revolutionized transportation and changed society and the geographic face of the country. American-born digital technologies unleashed a revolutionary new age of computing, communications and information mobility, disrupting industries and business models, changing society and culture around the world, and creating enormous new wealth. This continuum of innovation has delivered prosperity and rising standards of living to Americans, and propelled the United States to global leadership.

As we enter the third decade of the 21st Century, a new urgency, a new innovation reality, a new imperative faces the nation. The Council on Competitiveness has long characterized the competitive landscape, and examined where America stands. When major competitive opportunities or challenges emerge, the Council has sought to bring those to national attention, explore their implications and develop recommendations for action. Notwithstanding a currently robust economy – rising and strong economic, productivity and job growth; historically low unemployment; wage increases; an improved tax environment; etc. – the Council believes U.S. leadership in technology and long-term competitiveness is under threat. This potential demands the urgent attention of our nation's leaders, and a focused examination of our capabilities, investments and policies related to science, technology development and innovation.

The Case for On-Going Investment

While the United States is enjoying an economic upswing on many fronts, U.S. leadership in technology is under renewed threat. In 1960, the United States dominated global research and development (R&D), accounting for 69 percent share of the world's R&D investment. The United States could drive developments in technology globally by virtue of the size of its investment. Today, we have evolved into a multipolar science and technology world. As other nations have increased their R&D investments and capacity for innovation, the U.S. share of global R&D expenditures has dropped to 28 percent in 2016, diminishing the U.S. dominance and leverage over the direction of technology advancement. At the same time, China has risen to the account for a quarter of global R&D spending.

In addition, America's lead in venture capital is shrinking, further diminishing its role as a driver of technology and innovation globally. In 1992, U.S. investors represented 97 percent of the $2 billion in venture finance, and accounted for about three-quarters just a decade ago. However, in 2017, U.S. investors led 44 percent of a record $154 billion in venture finance, with Asian investors (with China leading) accounting for 40 percent. Moreover, while the absolute level of venture capital coming to the United States has increased substantially the U.S. share of the growing global pool of venture capital – which has increased more than 200 percent since 2010 – has dropped sharply from 95 percent in the early 1990s to about half in 2017.

While traditional U.S. competitors – such as Germany, Japan, France and the U.K. – continue to be strong R&D performers working at the leading edge of technology, many emerging economies seek to follow the path of the world's innovators, transform to knowledge-based economies, and drive their economic growth with technology and innovation. A growing number of emerging economies are establishing government organizations and ministries focused on technology and innovation, adopting innovation-based growth strategies, boosting government R&D investments, and developing research parks and regional centers of innovation. Some of these economies are also working to increase their production of scientists and engineers. These actions are raising technology and development capabilities and innovation capacity around the world.

A nation's R&D intensity expressed as R&D expenditures as a percentage of GDP provides another gauge of national R&D performance. In this measure, the U.S. position globally has lagged in recent years, as other countries have expanded the range and scope of their R&D activities. Notably, South Korea, one of the world's largest R&D performers and another formidable U.S. competitor, ranks at the top in this metric.

At the same time, key U.S. science and technology infrastructure is eroding. Much like roads, rails and power plants were essential for the Industrial Age, infrastructure that supports knowledge creation and technology development is vital for the 21st century knowledge economy and U.S. success in innovation-based global competition. This includes laboratories, research and technology demonstration centers, supercomputers, test-beds, wind tunnels, propulsion and combustion facilities, simulators, accelerators and other user facilities.

America's national laboratory system is considered a distinctive and globally unique competitive asset. But, across the system, core scientific and technological capabilities are potentially at risk due to deficient and degrading infrastructure and repair hamstrung by chronic underfunding, and maintenance backlogs in the hundreds of millions of dollars.

At the National Institute of Standards and Technology (NIST) – where I was recently appointed to a three-year term on the Visiting Committee for Advanced Technology -- more than half of the facilities on its two main campuses are in poor to critical condition. Forty-two percent of the space in its Boulder facilities is outdated or obsolete, with older laboratories there unable to support controlled environments required for advanced research. Other NIST facilities have experienced water damage, electrical failure and power outages. Facilities in poor to critical condition include those with capabilities in engineering mechanics, metrology, physics, materials, fluid mechanics and building research.

There are similar conditions in laboratories managed by the Department of Energy and the NASA. These "crown jewel" facilities in the national laboratory system are vital to U.S. global leadership across numerous science and technology disciplines. This infrastructure is absolutely vital to a future U.S. global leadership across numerous science and technology disciplines.

<u>New Disruptors</u>

At the same time that competition in technology and innovation is rising around the world, and U.S. technology leadership is under threat, we are witnessing accelerated advancement of the greatest revolutions in science and technology; a new phase of the digital revolution characterized by vast deployment of sensors, the internet of things, artificial intelligence (AI), and the big data tsunami; biotechnology and gene editing; nanotechnology; and autonomous systems. Each of these technologies has numerous applications that cut-across industry sectors, society and human activities. Each is revolutionary; each is game-changing in its own right. But they are now colliding and converging on the global economy and society simultaneously, with profound implications for U.S. economic and national security.

These technologies are crucial drivers of productivity and economic growth, altering the patterns of society and many dimensions of everyday life. For countries and companies, the ability to leverage these technologies for economic impact is fundamental to their competitiveness and economic success.

In addition to their economic potential, these technologies could solve many of the world's critical challenges surrounding areas such as health, energy and sustainability, clean water and the global food supply.

As Vice Chairman and Chief Scientific Officer of PepsiCo -- the largest food and beverage company in the United States – I am acutely aware of this potential. What goes into the creation of food and beverage products on a global scale requires serious STEM skills:

- Agronomists—people who study plants and soil—to help us manage and optimize crop yields.
- Engineers to build the lines and design equipment.
- Physicists who've mastered the laws of thermodynamics and fluid mechanics in order to make whole grain versions of extruded snacks like Cheetos.
- We need the expertise of chemists, flavorists, and food scientists —all scientific degree-holders.
- Nutritionists who work every day to improve the benefits of our foods and beverages.
- Toxicologists to ensure they're safe to consume.

We employ more than 250,000 people worldwide, including 110,000 who are directly employed here in the US and an additional 24,000 who work for our franchise partners. Every day more than 1 billion servings of our products are consumed per day by someone, somewhere in the world.

In 2017, PepsiCo was once again the largest driver of growth for our retail partners in the U.S., contributing 18% of total food and beverage retail sales growth – more than the next 15 largest manufacturers combined. Research and development is the engine that drives that growth and, accordingly our R&D spending increased 33% from 2011 to 2018.

We believe the disruptive innovation required to drive growth for a company of our scale will come from both internal and external efforts – putting the best minds to work unencumbered on our most serious challenges and greatest opportunities. Our ability to effectively recruit qualified STEM talent, establish mutually beneficial public-private partnerships to advance research and tap into a rich innovation ecosystem are essential to our success.

The New Workforce

The reorganization of the economy and society around powerful technologies is a dynamic process undertaken by business, government and individuals. It is inherently disruptive, both creating and disrupting business, markets and jobs. This dynamic process is essential to leveraging new technology to generate the greatest benefits in terms of jobs, economic growth, productivity and wealth.

Automation – robots, machines, devices, sensors, and software – is increasingly capable of doing routine tasks that have made up jobs for millions of Americans. In contrast, the labor market is rewarding the well-educated worker who can perform non-routine work and complex tasks. Higher-skilled workers are not only at a premium when new technologies are introduced because they are better able to use them, they are also better prepared to move to new industries, new jobs and new occupations or new skills when displaced by technological, labor market or market disruptors.

From technology to trade skills, there is no issue on which Council members are more united than in their desire for progress on building a talented, diverse workforce. As technology and the retiring baby boomer generation contribute to reshaping the jobs landscape, leaders must work at all levels, in the private and public sectors, to prepare Americans for the changes to come.

The Council continues to recommend several steps to address the talent shortfalls, urging both government policy action and partnerships between government, industry, academia and labor. America needs to take many steps, including: growing the number and diversity of its STEM-educated workforce, establishing greater opportunities for experiential learning (e.g. co-ops and apprenticeships), and reforming rules to retain more skilled immigrants. Other critical steps include encouraging greater lifelong learning opportunities, and re-establishing hands-on training classes in K-12 that build a base for skilled trade.

Optimizing the Environment for Innovation Systems

Since the early 2000s, new models of innovation have emerged, and others have matured in response to the transformation of the global competitive landscape that began in the 1980s. Multiple technology revolutions and their convergence, and the nature of global challenges require models of innovation built on internal resources, external collaboration and a larger, more diverse innovation skill set. For example, in a recent survey of U.S. manufacturing firms, of those firms that had innovated, 49 percent reported that the invention underlying their most important new product had originated from an outside source. These models of innovation have expanded the scope of participants in the innovation ecosystem, and the ways in which companies, innovators, and entrepreneurs pursue innovation.

As companies have moved away from exploratory research toward nearer-term applied research and technology development that support business units, foundational technology breakthroughs increasingly come from universities, national laboratories and small start-up companies that are disproportionately supported by public R&D investments. While the public role in the innovation ecosystem has increased in importance, U.S. public investment has not kept pace. This government investment plays a key role as the seed for future applied research and technology development, and for training the next generation of scientists and engineers. However, with increasing democratization of innovation, a growing pool of innovators and problem solvers are largely disconnected from the research, development and training institutions this public investment supports.

There are many factors that affect a country's ability to innovate and compete. This includes levels of investment in R&D, the availability of capital including venture capital to fuel start-ups and innovation at critical stages, the availability of talent, the environment for entrepreneurship, and the general business environment including taxes and the level of business regulation. These elements are different in countries around the world, and can play a significant role in a country's competitiveness and capacity for innovation.

U.S. competitors around the world seek to build and strengthen knowledge and technology-based economies as the basis for advancing productivity, job creation, raising standards of living and, in some cases, advancing geopolitical goals. As a result, many deploy policies and programs to harness science, technology and innovation, and to create a business environment to achieve this impact. These countries are instituting their own distinctive innovation ecosystems, which may not be compatible or friendly with the U.S. innovation system.

For example, in the U.S. the private sector dominates R&D spending and the Federal government spends significant funds on defense R&D and basic research. Other countries' R&D is dominated by government funding. The U.S. is home to many of the world's top research universities and a distinctive set of crown jewel national laboratories, while other nations are working to strengthen their university-based research and industry engagement with research institutions. The U.S. is known for its strong policies of technology transfer and intellectual property ownership of technologies developed with government funding. Other nation's science, technology and innovation efforts are strongly guided by national strategic plans, and many have high-level ministries devoted to stimulating technology and innovation. Many countries have national research programs or projects that target emerging technologies and fields. The strength of the start-up and entrepreneurial culture varies by country. In the U.S., state and regional governments play a significant role, with a wide variety of programs designed to stimulate technology-based economic growth, such as accelerators, incubators for start-up firms and seed funds. Other countries may deploy protectionist policies and illicit means to advance their technology positioning.

Can the U. S. Compete?

We are seeing changes in technology, competition and the global economy, historic in terms of their size, speed and scope. The U.S. faces hyper competition, a potential new global superpower competitor in China, and the prospect of economic and social disruption brought about by the unrelenting and accelerating march of technology.

Nevertheless, in a global economy ever more driven by technology and innovation, an enabling environment for innovation remains the advantage of only a few economies, with the United States in a position of significant strength:

- The U.S. remains the world's epicenter for disruptive innovation, thanks to its exceptional research infrastructure and low barriers to entrepreneurs and start-ups.
- The U.S. remains the world leader in high-tech manufacturing. It has a 31-percent global share and its output is growing. China is closing the gap with a 24-percent share and its output is also growing, surpassing Japan and the EU.
- The U.S. remains the world's largest investor in R&D for 28 percent of global R&D spending. It now invests half a trillion in R&D per year and has built up a globally unparalleled national stock of science and technology.
- Because the U.S. is by far the world's largest innovator in basic research, it dominates patenting, sowing the seeds of future innovation, representing about one quarter of all international patent applications filed in 2016.
- The U.S. has distinctive assets – its national laboratories and top research universities.
- In the U.S. innovation ecosystem, industry, start-ups, national labs and universities collaborate on R&D across the spectrum of science and technology.
- Vast amount of venture capital is pouring in to commercialize advance technologies.
- The U.S. is seen as the global technology leader. A recent survey asked researchers across the world which country they considered to be the global leader in 12 advanced industries. The U.S. was named most often in 11 of the 12 industries.

Despite these significant U.S. strengths, the competitiveness of a wide range of nations – not to mention economic and technological change – is dynamic and ever transforming. A country's comparative position can change rapidly.

When the U.S. controlled the direction of technology, we were positioned to control our economic destiny. That is no longer guaranteed. The United States must take stock. We must assess if our innovation ecosystems and investments are enough to maintain our global economic and technological leadership. And, as technology seeps into nearly aspect of American life, our national leaders and our government at every level must bolster their knowledge and response capabilities to match the strengthening competition, technological change an disruptions that are coming.

Conclusion

The United States is at a critical moment in time in national innovation systems research and action. New, transformational models driven by the democratization and self-organization of innovation are emerging and taking root across the nation. But, at the same time, U.S. leadership is under threat. The United States faces now what are perhaps existential challenges to its global leadership in innovation. America's role in technology advancement is diminishing globally—now accounting for only one-quarter of global research & development investments, down from two-thirds in 1960. Competitors are increasing their capacity for innovation. And rapid technological change and disruption have impacted the workforce and communities.

American voters agree with this sense of urgency. According to the results of a national poll, conducted by Hart Research and Echelon Insights, on behalf of a diverse group of organizations committed to advancing U.S. science and technology, including the Council on Competitiveness, 88 percent of voters believe it's important for the federal government to fund science and technology research and 75 percent would feel more favorable toward a congressional candidate who supports increased funding.

This voter support for federal science research is driven by a number of key factors, chief among them the fear that a lack of increase in science and technology research funding could weaken national security (90 percent), and that the U.S. is falling behind in educating youth in Science, Technology, Engineering and Math (STEM) fields.

With these challenges in mind, the Council recently launched a National Commission on Innovation & Competitiveness Frontiers to double down on all efforts to optimize the nation for this new, unfolding innovation reality. I am proud to serve as co-chair of this committee alongside Michael Crow, president of Arizona State University. Over the coming three years, the Commission will assemble top minds from industry, academia, labor and the national laboratories to:

- Sharpen national, regional and local leaders' understanding of a dramatically changing innovation ecosystem, and provide them a prioritized policy recommendation Roadmap for the coming decade;
- Harness changes in the global innovation ecosystem and implement the Commission's recommendations to accelerate and sustain annual productivity growth at levels between 3.5 and 4 percent, and push U.S. living standards (GDP per capita) to the top of global rankings by the end of the decade; and
- Address, propose and potentially launch private, public and public-private solutions to specific national and global grand challenges—as defined by the Commission's work.

The Commission will build on the Council's intellectual capital in this space developed over the past thirty years. Organized around three critical competitiveness pillars—capitalizing on emergent and converging technologies; optimizing the environment for innovation systems; and exploring the future of production, sustainable resource consumption and the future of work—the Commission will acknowledge and respond to the urgency of the challenge at hand, understand and describe this new reality and position the nation to prosper and thrive with a clear set of recommendations that will enhance and expand the nation's innovation capacities at the heart of competitiveness.

The Council's leadership firmly believes that with the right policies, the strengths and potential of the U.S. economy far outweigh the current challenges the nation faces on the path to higher growth and greater opportunity for all Americans.

We stand ready to work with you to set in place the policies needed to ignite a new era of competitive and sustainable growth and productivity.

Thank you

Mehmood Khan, M.D.
Vice Chairman and Chief Scientific Officer
PepsiCo

Dr. Mehmood Khan is PepsiCo's Vice Chairman and Chief Scientific Officer, Head of Global R&D. PepsiCo's businesses make hundreds of foods and beverages that are respected names globally.

Dr. Khan oversees the PepsiCo global *Performance with Purpose* sustainability initiatives, inspired by the fundamental belief that business success is inextricably linked to the sustainability of the world including agriculture, energy and water. He leads PepsiCo's research and development (R&D) efforts, creating breakthrough innovations in food, beverages and nutrition—as well as delivery, packaging and production.

Prior to joining PepsiCo, Dr. Khan was President, Takeda Global Research & Development Center, overseeing Takeda Pharmaceuticals Company's worldwide R&D efforts. Previously, Dr. Khan was attending staff endocrinologist at the Mayo Clinic and Mayo Medical School in Rochester, Minn., serving as Director of the Diabetes, Endocrine Trials Unit.

Dr Khan has been recognized by academic and international organizations including honorary doctoral degrees, the Ellis Island Medal of Honor, Career Achievement Award and Pinnacle Award and is an elected Fellow of the Royal College of Physicians, London.

Dr. Khan is a member of the Board of Directors of Reckitt Benckiser , Life BioSciences and Indigo Ag. He serves as Chair of both the US Pakistan Business Council and the U.S. Council on Competitiveness in Washington DC and is member of the Board of FFAR, US Department of Agriculture and the Visiting Committee for Advanced Technology at the National Institute of Standards and Technology. He also serves as a Judge for the Lemelson Innovation Prize at Massachusetts Institute of Technology.

Dr. Khan lives in Greenwich, CT with his wife Shahida. Together they have two sons, one daughter and three beloved grandchildren.

Chairwoman JOHNSON. Thank you very much. We'll begin our first round of questions, and I want to say to Members of the Committee that are present that if you have statements—opening statements, you can be—place them in the record, and each of us will have questions as we go around.

[The prepared statement of Mr. Posey follows:]

SST Full Committee Hearing
Subject: "*Maintaining U.S. Leadership in Science and Technology*"
Wednesday, March 6, 2019 at 2:00pm, 2318 Rayburn
Rep. Bill Posey Statement and QFR

Madam Chair, thank you and Mr. Lucas for holding this important hearing. U.S. leadership in science and technology is vital to our leadership in innovation across both government and our private sector economy.

The material and witness testimony for this hearing documents the important roles and contributions of the public sector, universities, and private industry to sustaining our leadership in science.

I represent the Space Coast of Florida, home to NASA's Kennedy Space Center and Cape Canaveral which might be rightly called "the Kittyhawk of Space." Science and the work that goes on at the Space Center are tightly linked.

The National Science Foundation lists the Research & Development expenditures of the federal agencies in its Science and Engineering Indicators report.

For the latest year they reported – FY2016 – federal expenditures for R&D were about $143 billion. About $101 of that total was for the two big ticket items of defense and health. Of the remaining $42 billion in federal R&NASA R&D accounted for about $12.1 billion – about the same size as the Department of Energy – just a tad less. So, NASA was about 30% of our federal non-defense, non-health R&D budget. And roughly 70% of NASA's R&D money is spent outside the agency. These figures measure the importance of space program R&D.

The Indicators report we are discussing today also says that with 20.9% of our non-defense R&D devoted to space, we lead the world in space R&D. I certainly support maintaining that leadership.

Much is also being spent on space R&D by our private sector. And the fruits of those efforts are apparent in the exciting and dramatic launches like Falcon Heavy we've been seeing at the Cape. This activity can only grow with the vibrant partnerships we have between the private sector and NASA.

As you know the International Space Station is now part of our National Laboratory system – the ISS National Lab. And through that Lab, we are beginning to see the future of science IN Space, as well as space travel through science.

Our space program is back, and we are just beginning this new and exciting era of exploration, commerce, and scientific research.

It's hard to determine, actually, where I want to go, but I'd like each of you to comment. I feel, frankly, that we're at a crossroads, and the next 10 to 20 years will determine whether we're going to remain competitive. And try to see if you can give me three or four major points that we must accomplish to catch up and stay ahead of our competitors outside this country. I'll start with Dr. McNutt.

Dr. MCNUTT. So I mentioned three of them, and the three being we have to start recruiting, in a way that we haven't been able to so far, a fully diverse workforce domestically. The second one is we have to keep our doors open to the very best and brightest internationally, and not inadvertently turn them away. Third, we have to maintain an investment in—financial investment in the R&D enterprise, particularly in high-risk, high-reward work. Whether it's basic research or applied research, it doesn't matter, but that's the kind of work—I talk to so many people who gave me examples of breakthroughs that were turned down by our Federal agencies, and they had to cobble together other funding in order to get it to happen.

So I think those are three top ones, but I also would—now that you asked me for more, I would also say that one reason why so many of these international students look so good is that they have education programs that start at 5 years old, training these students so that they are super prepared for a career in science and technology, and they do not stop anywhere through their education program. And we don't do that as well.

Chairwoman JOHNSON. Thank you. Dr. Gallagher?

Dr. GALLAGHER. So, Chairwoman, I'll actually answer as if I was sitting in your chair a little bit, in terms of what the priority should be. I think—I agree with you, this is a pivotal time. I would say we need a goal. One of the interesting things I would say is that one of the reasons that these developing countries have made such progress is they lit their hair on fire, and made this a national priority, from their perspective, to copy, emulate, and to scale up a U.S.-style S&T enterprise in their countries. It—they are top priorities. They have mobilized their resources to do it, and it reminds me of times when the United States did the same thing. Our post-Sputnik response was a massive R&D investment and commitment that went beyond just the funding, but to getting the country excited and focused on STEM and production, and I think it's time for a goal, a national goal, for why this is important.

The second thing I would say is that the U.S. S&T enterprise has been based on a partnership. It has always been, for the last 70 years, a partnership between industry, universities, and the Federal Government. Our national labs were set up when industry mobilized and managed them for a dollar to meet national needs. The Federal Government agreed to provide the basic support to—on science. The universities agreed to be both basic science performers, and to train the next generation, and I think we have to look to the health of that partnership. I think there are signs of it pulling apart a little bit.

And the last one is that I don't think there's a silver bullet easy fix to this. Our competitors are doing this by writing 5-year plans and taking a sustained strategy over time. So I think what we need, in addition to that goal, is a sustainable commitment. Hope-fully a bipartisan commitment, but certainly a national commitment about why this is in our best interest, why we make these investments in our national treasure, and why this is so important to our vitality as a country.

Chairwoman JOHNSON. Thank you. Dr. Khan?

Dr. KHAN. Let me build on my colleagues. I, again, would emphasize the investment in government-funded research, but in particular foundational research, as the pipeline of the next generation of ideas, and we need to prioritize. We can't do everything, but we have to figure out what is of strategic importance to us as a country. I would emphasize not only the increasing training required, and diverse, but we have to come up with new training models. We cannot fill this gap that is coming in our technical workforce in the next 5 to 10 years using a traditional model. And I think this is where industry, public and private partnerships, have to come together and say, are there greater efficiencies to be had in our educational model that will fulfill our workforce requirement? There are thousands of jobs available today which aren't being filled because we don't—we have a skills gap, and those jobs need to be filled today. It takes years to create, so we have to do both. And how do we do that?

And the third is, do we have the policy framework for the right public-private partnerships and transfer of research and knowledge efficiently and as fast as possible so that we can benefit as a society from the investments being made by government. A lot of great ideas that sit within our national laboratories within our system that we in industry could use today, and commercialize, and bring economic value to the country. What would it take to do that?

Chairwoman JOHNSON. Thank you very much. Now I'll call on Mr. Lucas.

Mr. LUCAS. Thank you, Madam Chairwoman. And, continuing on that line of discussion, Dr. Khan and Dr. Gallagher, in Oklahoma my universities tell me that they have 2,000 open engineering positions, jobs, in the State, more than the local engineering departments can currently produce. Continuing down this course about how industry and academia, from their perspective, can work together to meet that demand—and we're talking about Oklahoma. Two thousand more engineering jobs than they can create the engineers for. Would you continue to expand on where you were headed there?

Dr. KHAN. Well, I think there's—there are a number of approaches we can take, and each has a, you know, each situation is different. So, with that context, some cases we, as an industry, are going to have to look and say, what level of education is required to fill a certain job, or can we retrain an individual to that specific job? But then, if we're going to retrain them, through an accelerated program, to be able to do the job, who do we partner with? What will it take? How do we do that? I'll give an example. I can't—we have challenges filling jobs with food safety—just to do auditing. Can we partner with a university? We at PepsiCo recently just partnered with a university and said, can we do a 12-month training program in order to fulfill the needs? It's not a 4-year degree, but can we, in 12 months, get them ready for that? There are different models. That's one.

The second is can we train people in the job to get academic credentials? So while they are fulfilling their day job, what will it take for them to get the advanced credentials, and which universities can we partner with? So I'll give you those two as examples, because many of these are working people with families. I have many employees, in particular women, who are at a career stage where, early in their career, they did not go and get an advanced degree. Now the children have grown up, but they can't leave the workforce. I can't afford for them to leave, and they can't economically do it. What will it take to get a graduate degree or a Master's in Engineering on the job? Using our own laboratories, maybe—these are all ideas. I think we have to work together to explore those, but I'll defer to Dr. Gallagher.

Mr. LUCAS. Dr. Gallagher?

Dr. GALLAGHER. Your question reminds me—I remember when I was in the Commerce Department, and I was talking with some CEOs, and they sounded just like your question. You know, there's this huge demand, we can't find this talent. And then the next day I was talking with some labor economists, and they said, no, that's not true. I said—they said, those guys aren't right, because if you look at the salaries and other things, we're seeing no signs of a workforce shortage. And, of course, there's data that suggests that as well. I think this mismatch we have about being—we all want to be market sensitive. Universities want to produce what's needed, and there seems to be a lot of evidence that those market signals are not very good right now.

One of the things that may be happening is that fields like engineering, that are actually quite broad—when industry says they need engineers, they're actually talking about a specific type of engineer, and there's a gap between sort of the general degree and the actual skillset that's needed. And so this—there's a gap between the educational space and the workplace. The one obvious place where that can be addressed is to bring those two worlds closer together. And that's why I said this partnership model was built when—I know when I went to school, the companies that were doing R&D were right in our labs, collaborating with us. There was a lot of shoulder rubbing. And I think, whether it's the undergraduate level, or up through the graduate and professional training level, we have to make sure that those two worlds sit side by side. That's probably the best way to address this gap.

Mr. LUCAS. In my remaining time, to anyone on the panel who would care to discuss it, in my opening statement I mentioned the need to better explain the value of the Federal investment in science and technology to all of our fellow Americans. From the role I sit in on this side, I have to justify every penny when we deal with—as authorizers with the appropriators, and we deal with the various taxpayer-sensitive groups back home, and we deal with the citizens who come to our town meetings. Just for a moment, if anyone would care to touch on this, how we do a better job of explaining the story, the connection, that science has to the real world for our folks back home, the real people?

Dr. KHAN. Let me give two very easy—one is look at the competition. If there wasn't value, then—just about every emerging country and developed country is aggressively competing for R&D centers. As a global company, as a global organization, wherever I go, the first question I get is, will you build an R&D facility in this country? And that takes a very high priority, because R&D investment not only creates the number of R&D jobs, but the domino effect, and knowledge transfer, and the ability, then, to leverage it into the economy comes right at the top of the list. So that's number one.

The second is the fact that, as we look at all of the new jobs that are being created in this country, as we speak today, the vast majority are on the back of new technology that was actually developed in this country. The Internet, developed by the Federal Government. The digital age. Everything—the examples I gave you all came out of technology that eventually became industries.

Mr. LUCAS. Panel's been very insightful. I thank you, Madam Chairman, yield back the balance of my time.

Chairwoman JOHNSON. Thank you, Mr. Lucas. Now I call upon Mr. Lamb.

Mr. LAMB. Thank you, Madam Chairman, and I want to extend a special welcome to Chancellor Gallagher, the Chancellor of the University of Pittsburgh, and I, like you, remembered to wear my Pitt colors today, so we're very proud and happy to have you here. You have done a fantastic job, and your testimony today highlighted a couple of important things, one of which is the fact that we have a long way to go when it comes to advanced manufacturing, and preparing that pipeline of talent, the material science, but also preparing the workers themselves who will be taking those jobs in the future. Obviously, I would love to see Western Pennsylvania play a leading role in that, as I know you would.

One of the things that you stressed in your testimony, and the Brookings report that you referred to talked about it as well, is the role of the manufacturing institutes in preparing us both on the scientific side, but also the pipeline of workers that we'll need. Can you talk a little bit about how the Advanced Robotics Manufacturing Institute in Pittsburgh has helped, maybe the one in Youngstown as well, our neighbor, and how we could improve those to maybe build on the partnership that you keep talking about between industry and the universities and the government?

Dr. GALLAGHER. Great, thank you. And thank you for wearing the tie. I always appreciate that. So one of the reasons we keep focusing on manufacturing is, I think, always surprising to people. It's not just the making of things, and the workforce issues. That's often sort of that view that we get. The reason manufacturing, in my mind, is so important is that, in the United States, if you look at all of that half-trillion dollars R&D spend that we make every year, almost three quarters of that—we're approaching $3 on every dollar that the Federal Government placed. So the private sector side is now the dominant amount of R&D spend in the United States. And if you look at where that's coming from, it's predominantly from manufacturers, R&D intensive manufacturers, and that's where this R&D—this advanced manufacturing comes from.

So this is as much about the knowledge economy as it is about where things are made. There is where the know-how is. But it also has an outsized effect on our traded economy, the balance of goods, on our middle class, so there's a lot of very strong economic reasons why the advanced manufacturing sector is there. Here's the problem I see. Despite the fact that the private sector's R&D has grown faster than the Federal Government's—so we went from a time, during the peak of the Apollo, when the Federal Government's expenditures were larger than the private sector to now one where they're three times larger, is that the makeup has shifted.

The—where the money goes from the industry side now is largely focused on late-stage R&D and development, whereas universities now are specialized more on the basic R&D side, so the two worlds are actually quite far apart. And of the challenges—can we bring them together? So you could certainly have universities try to do industry-like things, and, of course, entrepreneurship and other things is a way of pushing them to get more commercial, but part of the strategy should be, how do you pull industry toward the universities?

The idea behind those institutes was to get industry—a number of industries together, like a consortia, identify a pre-competitive agenda, one that they're willing to share, and that tends to be, you know, less sensitive, and something that the universities can work with. And so the idea behind the institutes, if you think about it, was a consortia with a lab. I think they've been remarkably successful, but they're quite young. For me, the litmus test of success is do they—are they sustainable, and does industry see a value in sort of moving decidedly in funding this pre-competitive window, and does that attract that shoulder rubbing I was talking about between the universities and the world of industry?

Interestingly, this—these workforce issues we see in manufacturing are, you know, who brokers that? One of the exciting things, I think, is that these consortia have often looked—a lot of the employment comes in the supply chain, but once you have a consortia, the consortia often takes ownership over that supply chain. We saw that with Semetec and the chip manufacturing. A lot of that R&D investment that the chip manufacturers made went to the supply chain that made the tooling, and other advanced instrumentation. So I'm hopeful that they also become a powerful way of supporting workforce growth and training in the supply chain, which is where most of the employment is.

Mr. LAMB. Thank you very much. And, Madam Chairwoman, I yield back.

Chairwoman JOHNSON. Thank you very much. Dr. Babin?

Mr. BABIN. Yes, ma'am. Thank you, Madam Chair. Thank you for being here, all of you. As the Chairman of the Space Subcommittee for the previous two sessions, and the Ranking Member of the Space Subcommittee now, I would ask you about public-private partnerships, and I would address this to you, Dr. Khan. When we look at what NASA has done by partnering with industry to support commercial space, allowing NASA to focus on other priorities, like deep space exploration, do you think that public-private partnerships like these may be a tool to address U.S. competitiveness in cutting-edge industries of the future, like quantum? Are other nations investing in public-private partnerships in these fields? If you would briefly give me your thoughts?

Dr. KHAN. Well, other countries definitely are investing in these public-private partnerships, and they're—frankly, having learned from the U.S. as a pioneer, have created, and emulated, and modeled, much—examples of this. However, we remain the leader simply because of the installed infrastructure, the network of our academic and national labs, as I mentioned, but the application of this really comes to life from a—from my perspective, because, unlike an academic discipline, where you may have 5, 6, 10 disciplines looking at individual components of the science by necessity, we, as industry, don't say to a university, give me, and I'll give a very simple example, the next generation of this polymer. We go and say, I want a sustainable package for food which will keep the food safe, and will keep it clean, and I can put it into my supply chain, and manufacture it at high speed in 10 locations. That's a real world problem.

I can, however, go to a great institution, and there's a number of institutions, as well as national laboratories—not easy today to get a national lab or university, maybe more than one university to say, that's the problem I need to solve.

Mr. BABIN. OK.

Dr. KHAN. And there you can bring the consortium together.

Mr. BABIN. All right. Thank you very much. And then, second, I'd like to address this to you, Dr. Gallagher. Our intelligence community has warned Congress about the threat of foreign espionage in our science and technology arenas, particularly on university campuses. Given this challenge from our adversaries, and particularly China, how do you suggest that we better protect our American campuses, our research, and our leadership from this threat? I just read an article on Confucius Centers just yesterday, and this is a very big threat to our national security.

Dr. GALLAGHER. So one of the flip sides, you know, of the S&T and T enterprise is that it's about science, and it's—in the context of science, knowledge is a good thing, and we want it to be shared as broadly as possible, but it's also science that's useful to us for these national purposes, and so we derive things that are quite sensitive. Things like I—intellectual property, national security information, and other things. So managing this tension between when is the S&T producing open knowledge, and when is it producing knowledge to be protected, is really one of the great challenges.

This segregation is actually one way we managed it. Universities, by and large, do very little intellectual property-intensive work, and very little classified work. We don't do any classified work at the University of Pittsburgh. And so that has led them to sort of have a—an architecture that's more open, and where information's more widely available. And, of course, if you went to a company, things would be locked down more tightly. What's happening right now is this boundary between sensitive information versus open information is becoming blurrier, and I think the highly competitive interaction between the U.S. and China is making us re-look at the risk proposition. When——

Mr. BABIN. Absolutely.

Dr. GALLAGHER [continuing]. We were dominant, we were probably more willing to share. So I think this is an area where we're looking for clearer guidance from the government. I think one of my big concerns now is we're reacting to the concern, but really without a policy strategy. And——

Mr. BABIN. OK. I——

Dr. GALLAGHER. Important topic, yes.

Mr. BABIN. All right. Thank you very much. I've got one more question, and I want to address this with you, Dr. McNutt. I'm hearing the point repeatedly made that for America to maintain its leadership in science and technology, it necessitates an influx of funding, an increased investment, in other words. Given that the debt situation domestically, currently at $22 trillion, and Congress's obligation to be prudent stewards of the taxpayers' dime, at whose expense should we make this commitment, and what should be cut in order for us to focus more on our science and technology? I'd like to hear your thoughts.

Dr. MCNUTT. So—thank you for that question. So I don't necessarily think that we need to ramp up greatly the investment in science and technology. That can actually be not a good thing for science, when you have, for example, huge increases in budgets, and then they level out, because then you create a new workforce, and there's no place for them to go. But steady funding for science is important. So I think what I'm more concerned about would be a rapid decrease in the science budget due to, say, sequestration caps. So steady funding of science is much more important than the vicissitudes of funding, which can happen when we don't do long-term planning.

Mr. BABIN. I understand.

Dr. MCNUTT. And I also think that how we spend the money, less incremental science, much more high-risk, high-reward, the kinds of things that are much more likely to lead to breakthroughs and new industries.

Mr. BABIN. Certainly. Thank you very much. I yield back, Madam Chair.

Chairwoman JOHNSON. Thank you very much. Mr. McNerney?

Mr. MCNERNEY. Well, I thank the Chair, and I thank the panelists. A very interesting discussion today. And I want to sort of appreciate your comments, Dr. McNutt and Dr. Gallagher, on the continuity of funding. I spent 25 years developing wind energy technology. Some of that was funded by the U.S. Government. Funding and support fell off. The technology we developed, with U.S. funds, went overseas. I saw that happen with my own eyes, so I think that's a very important point to make, and to continue to make.

Dr. McNutt, as you may know, the NAS is beginning a study on climate intervention, governance, and research, including atmospheric sunlight reflection. Can you talk about ways we should be supporting basic science research to combat climate change?

Dr. MCNUTT. So that study is a follow-up to an earlier study, which talked about the fact that we may find ourselves in a situation where our backs are against the wall, and we simply do not know enough about these potential solutions to know whether they are worse than doing nothing.

Mr. MCNERNEY. Right.

Dr. MCNUTT. And, in particular, the governance situation is unknown at this point because there are no international laws that would prevent someone from deploying albedo modification, for example, to control climate. And so you can imagine a situation where a single nation could alter the albedo because they're concerned about their climate. In doing so, they could make it worse for five other nations.

Mr. MCNERNEY. Right.

Dr. MCNUTT. No one could stop them, short of, perhaps, some kind of military intervention. And that might not be a good outcome, which is why we need to study this problem.

Mr. MCNERNEY. Thank you. Dr. Khan, China has made it clear that they intend to be a leader in AI (artificial intelligence), and, as the Chairman of the AI Caucus, I'm focused on the safe advance of U.S. AI technology. What, in your opinion, is needed to maintain U.S. leadership in artificial intelligence, and how would you describe the consequences of ceding leadership?

Dr. KHAN. Well, I think the second part of your question is easier to answer in some respect, because if we look at everything from the next generation of manufacturing, to health care, to agriculture, to any industry we can look at, AI is already playing a part in the development of that industry. And, in the absence of our leadership, then we cannot operate as a leader. So AI, to me, is a tool that allows us to operate in the next generation, and discover the solutions of the next generation, whether it's environmental, or any other aspect.

In terms of the first, we have to be consistently supporting the development of those technologies, just as Dr. McNutt said. The challenge is not just the quantity, but the uncertainty with which that funding comes, and we have to prioritize it. There's no other solution, and, in fact, I don't think we have a choice.

Mr. MCNERNEY. Thank you. Dr. Khan, I just want to talk about the economic deterrence of going into STEM fields. It takes years of graduate school at very—survival wages. It takes years of post-doc at meager salary. When you become a researcher, a full-fledged researcher, you have debts. Your contemporaries are way ahead of you financially. You've spent years in your basement, inverting functional matrices, or whatever it is you do in your research, while your contemporaries are out there having fun, or doing—partying, whatever they do. So what are we going to do to change that model so that students want to go into these fields, and not have to worry about ending up behind the eight ball?

Dr. KHAN. I thought you were describing my early life. I spent 8 years as a trainee after medical school, so I personally know that. And, by the way, my wife's sitting behind me, who can vouch for all those tough years. Look, we have to figure out a funding model that makes education—the availability and access to education has to be democratized in a way it's available to everybody. And if we're going to get to a state where we have a diverse, educated workforce, it has to be on the basis of the fact that, regardless of your means, at some point you have at least that at your availability. I will defer the solution to that to the Members of this Committee.

Mr. MCNERNEY. Just a simple yes or no, Dr. Gallagher, is our patent system part of our problem?

Dr. GALLAGHER. It's certainly an element in it, yes.

Mr. MCNERNEY. Thank you. I yield back.

Chairwoman JOHNSON. Thank you very much. Mr. Waltz?

Mr. WALTZ. Thank you, everyone, for coming today, for testifying—this critical issue. Dr. McNutt, you mentioned in your testimony women in STEM, in science, in technology. I agree with you, we've made gains. I don't think we've made enough. I think incentivizing women to have interest, and pursue careers in STEM is critical to fully utilizing our talent base, and competing long term. And, in fact, it's not just about competitive, it's not just a domestic issue, it's an international issue. It's a national security issue, in my view. And in my background as a Green Beret, and operating all over the world—I mean, the bottom line is where women thrive in business, in civil society, in politics, extremism doesn't. Not to be sophomoric, but I think that's just my experience.

So the question is, how do we make STEM education more attractive, interesting? How can this body assist? Why are more women not attracted to this field, and how can we continue to move that forward?

Dr. MCNUTT. Well, thank you for that question. I used to think, very naively, that the reason why we had this leaky pipeline problem—we saw it in many fields, my own field in particular. Fifty percent of the students in graduate school were women——

Mr. WALTZ. Um-hum.

Dr. MCNUTT [continuing]. And it had been that way for a long time. Why weren't we seeing them come out the other end into the associate professors, and the full professors? It wasn't happening. I thought it was just a quality of life issue. Maybe they're too smart to be stupid like us, and think that a, you know, career in science was a lot of fun. And then my eyes were opened by this report that the National Academy of Sciences did, that showed that there is this undercurrent of harassment for women that is—that has gone underground. That—it used to be out in the open. It went underground, that was just the—dear, you don't really belong in science, do you? Or wouldn't you be happier doing this instead? You know, and it was just—or the little put downs that were discouraging to many women. And we just have to stop that.

And it—of course, it happens everywhere. It happens in law, it happens in business. But it's worse in science, and the reason it's worse in science is because of this indentured servant model, where students come in, and they're attached to a supervisor who is responsible for their funding, for their research project, for their recommendations after they graduate, and it makes it much more difficult for them to cut loose in a bad situation.

Mr. WALTZ. Dr.—didn't mean to interrupt you. Just, in the interest of time, I would be interested in follow up on how we can——

Dr. MCNUTT. Yes.

Mr. WALTZ [continuing]. How we could help.

Dr. MCNUTT. Yes.

Mr. WALTZ. Dr. Gallagher, I'm interested in your comment a minute ago about guidance when it comes to the Chinese, I mean, frankly, just stealing our IP (intellectual property) and our technological edge across the board. I'm also on the Armed Services Committee, and it is just wholesale theft, in their national interest, and certainly not in ours. So what guidance do you need? Do you need a categorization of what is considered sensitive? Do you need standards on what needs to be protected? I certainly don't want to limit the growth of—and your freedom, but what do you need?

Dr. GALLAGHER. So—yes, my take is that the exfiltration of American IP and sensitive information to China has been happening for a long time. This is not a recent phenomenon. And so, you know, lack of enforcement, lack of, you know, protections. I think some of the positions that U.S. companies have been put, where they have to operate in China, and they have to, you know, basically spill over——

Mr. WALTZ. I think the Administration's getting at that pretty aggressively.

Dr. GALLAGHER. The—but the flip side is it's also been part of U.S. science policy for a long time, in fact, since the opening of China in the 1970s, that science was a form of scientific diplomacy, that we wanted to be there openly, and collaborating, with the hope that the Chinese, at one point, would be contributors to the knowledge commons of fundamental science. So in some ways that's happening as well. They're now producing papers, and actually contributing. So we have this dilemma where the competitive nature of China with the United States, whether geopolitically or economically—the question is, does that mean we should stop collaborating on the science side as well? And that's where I think there's——

Mr. WALTZ. Well, I'm asking you.

Dr. GALLAGHER. I—my instinct is no. I think that there's a win when—because most science has been done with broad open collaboration. The rising tide rises all boats, and I would much rather see the U.S. not subsidize the technology around the world. We'd like to see more countries contribute to basic science. The problem is matching those concerns we have when it becomes specific nationally related or commercially related information with this window when it's presumably open, and all for the good.

Mr. WALTZ. Thank you.

Chairwoman JOHNSON. Thank you very much. Mr. Bera?

Mr. BERA. Thank you, Madam Chairwoman. You know, what's remarkably refreshing is I really can't tell who the Republican witness is and the Democratic witness—because I agree with all of you, and there's so much that we could talk about.

Dr. McNutt, you talked about the best and brightest coming to the United States, and our history is that of a Nation of immigrants. If I think about my own story, my parents came from India in the 1950s to get their education at USC, and then they stayed. If, you know, Googling this, 55 percent of American billion dollar startups have an immigrant founder. Thinking about Google, Sergey Brin was an immigrant from Russia who went to Stanford on a PhD graduate fellowship that was funded by the NSF. These are smart investments that we ought to be doing more of.

Dr. Khan, as a lifelong Californian, I paid $393 a quarter to go to medical school at the University of California, Irvine because we made a conscious decision in California in the past that we thought investing in education—and, if you had the talent and desire, we—you ought to invest in your best resource, your people. We stopped doing that in the mid-80s and 1990s, and, you know, it—and we're living off of the residual, in California, of those investments—we made in the 1960s and 1970s.

If you think about then—the University of Pittsburgh's a wonderful institution, but I'm a University of California guy, and, you know, if you think about the remarkable economy in California, they're all built around our universities, our research universities. There's a reason why Silicon Valley exists where it does. You know, the remarkable work that's coming out of the University of California, Davis, my home institution, you know, around the Ag, water, that sector, these are smart investments, and we're just not doing it.

If I think about, you know, a couple things that came up, we've got to re-think education, right? Both in the K through 12 space, but also our 4-year education graduate degrees. And, you know, if I think about it, when I was Dean of Admissions at UC Davis, we tried to revamp medical school training, because it's an outdated model. Now, you run into huge faculty issues and institutional barriers. Maybe each of you, if there's one or two things that we could do to modernize higher education, what would those tools be? I don't—we'll start with you, Dr. Gallagher, because you're in the midst of it right now.

Dr. GALLAGHER. Well, one of the biggest things that I think many of us are navigating is there's a pendulum swinging back and forth between whether education is a private good, in other words, it's the student who benefits with the degree, and therefore they should pay for it, or whether there's a collective or public good to our society by having—and you see that being played out in the levels of State support, for example, which has been the—historically where institutional support went. So Pennsylvania's sitting number 49th in the United States in the level of public support to the universities, and as a result Pitt is, I think, one of the most expense, if not the most expensive, public university in the United States. Not something we're proud of.

There's—I—the most frustrating thing, I think, before we get into reinventing higher ed, is we have to reach some consensus on whether this is merely a public good or a private——

Mr. BERA. I think, you know, we spend a lot of time thinking about the future of work, and those areas of the country that are falling behind, versus those areas that are going to be resilient and thrive, again, the coasts and the big cities—yes, MIT's doing some pretty interesting research here, those characteristics. There's always an academic research center in the—so I would argue it's a public good, if not an economic good. And one of my colleagues talked about the investments, and I'm very concerned about the debt and the deficit, but we never talk about the return on investment, had we not invested in those—and I think we've got to do a better job explaining, you know, that return on investment. Dr. McNutt?

Dr. MCNUTT. Yes. If I could reimagine what I'd like to see as the future of higher education, we'd stop thinking about higher education as a 4-year, one-and-done kind of thing, that higher education becomes a partnership between American industry and the universities, such that people view higher education as a continuing process that they're always doing, so that people are always on the cutting edge, such that they always feel prepared for whatever comes next, and that industry is helping to inform universities what they need out of their workforce, and people feel a lifelong connection to these institutions.

Mr. BERA. And, you know, if I think about the PhD students that I trained with, they were going into academia. The PhD students today are going to go into industry, and I think we've got to do a better job.

Dr. KHAN. Well, I hope they go into both. And, again, to Dr. Gallagher's earlier point, coming back to the fact that industry is funding more research than the government is is not a good thing. I don't celebrate it, as an industry person, because my research is applied, and I can't do applied research until I have the basic fundamentals, so—but from the educational model, I want to just build on Dr. McNutt's point, which is most of us are not doing a job that we were trained to do when we were in academia. That is just—I think, if you look across this room, I doubt anybody in this room had a degree in how to be a Congressman. I certainly didn't have a degree on how to be at a food and beverage company.

And I think the key here is that we train a workforce that has the plasticity and the learning ability for lifelong learning, so that's the internal that we have to do, and then a culture that actually nurtures that. It's going to take both, which is where the policy part comes in. I think if we don't do that, especially in the rate and pace of change that we're in today, the world expects that we will re-educate ourselves, and have multiple careers. And if we couple that with the population demographics in the United States today, and in many parts of the world, our population demographics are such that we're going to have, with the Baby Boomer population, a large number of people who are able to work, but need to be retooled, and the economy needs them, and industry needs them. We need that partnership. So education coming—bringing it to life, exactly what Dr. McNutt says, they're our absolute necessities. We don't have the framework right now to do that.

Mr. BERA. Great.

Chairwoman JOHNSON. Thank you very much. Mr. Gonzalez?

Mr. GONZALEZ. Thank you. Thank you for your testimony so far. This has been a fantastic hearing, so—just really appreciate all the work that you've put into it. Couldn't agree more with the last topic you were just talking about it, which is we need to instill a culture of lifelong learning, and our education system needs to reflect the realities of the 21st century economy, where we're—forget jobs, we're popping in and out of industries multiple times over the course of our career. So I fully agree with that.

If I could, to start, Dr. McNutt, I want to build on Mr. Waltz's question. I think you framed the problem incredibly well, in terms of, you know, what's pushing women out of STEM fields, and then he asked the question—well, he didn't have time, but could you expand on what you think this Committee could do to support women in STEM education, and in industry generally?

Dr. MCNUTT. Right. So the report makes the point that changes need to happen—this is the National Academies report on sexual harassment for women in the science, engineering, and medicine fields—that the main changes need to come from changing the culture. We have to change the culture of our institutions. And changing the culture within our laboratories, our Federal laboratories, changing the culture within our funding agencies, changing the culture within our universities. All of these systems need to have a topdown culture that starts with statements like, sexual harassment, gender harassment, will not be tolerated.

I remember many years ago the Federal Government, through OSTP (Office of Science and Technology Policy), but I think well with the support of Congress, made scientific integrity a priority. I think that the government should make the banishment of sexual harassment a priority as well, and make every single agency come up with a plan for how they are going to change their culture to make sure it doesn't happen. And have your funding that you give to them contingent on having that plan.

Mr. GONZALEZ. Thank you. And then, switching back to education, specifically in communities not on the coast, right? So I come from Northeast Ohio, and we have a pretty big skills gap when it comes to STEM. According to a recent estimate provided by McKinsey and Company, Northeast Ohio has the potential to receive an economic impact of between $3.5 and $10.1 billion annually by year 2025 through the implementation of things like Internet of Things, various manufacturing application segments. What we lack is a workforce that has the tools to take full advantage of these opportunities.

So what would you say, and anybody can answer this, would be the right way that we should be thinking about this in Northeast Ohio, as we train up our workforce for the 21st century? Dr. Gallagher, please.

Dr. GALLAGHER. Yes. Let me—I think one of the ways I think about this—in fact, it goes back to the Ranking Member Lucas talking about farming. You know, when the United States started industrializing, one of the things we did as a country was rather dramatic. We made mandatory elementary school, right? And we decided that the population, to be able to adapt to this economy, needed to have basic literacy and math skills to be able to focus on that. I think a similar thing is happening. These knowledge-based economies—the good news is that the knowledge moves pretty well, and broadband, and infrastructure, and computing, the, you know, I don't think the proximity to the few top, most R&D intensive universities is the only way that our society can benefit. But I don't know if people have the skills in basic digital literacy, those core competencies that they can, you know, productively and agilely work in that economy.

Mr. GONZALEZ. Great. And then, final question, and I think this was Dr. Khan who mentioned that the industry–university government synergy has kind of broken down, or was that you, Dr. Gallagher? That was you? OK. So, if you could, you know, just describe some ways that we might be able to piece that back together, because it strikes me that that's a critical component here.

Dr. GALLAGHER. Well, I think it's, you know, the government has tended to fund the universities, so a lot of the mandate has gone on the universities for how can they be more relevant to industry? I think the uncracked code is, you know, who's talking to industry about the partnership working the other way as well, and creating some of those dynamics where, you know, companies that are working very hard on competing and working on pretty sensitive technologies can find a place where they can move upstream, take some of that higher risk, but higher payoff, more fundamental work, and work alongside the universities. That could be in consortia, other types of partnerships. I think asking the funding agencies to look at how that would work, and how some of those cost sharing arrangements could be incentivized.

We've stimulated the amount of R&D spent by industry with the R&D tax credit and other things, but we haven't really tried to shape where some of those investments are, and I think that's an interesting policy arena.

Mr. GONZALEZ. Got it. Thank you, and I yield back.

Chairwoman JOHNSON. Thank you. Ms. Horn?

Ms. HORN. Thank you, Madam Chair, and thank you, all of you, for this fantastic hearing today. There are many things that I want to talk about, so I'll try to keep it focused. The questions have been fantastic. A couple of things. I've heard consistently from all three of you about three challenges, concerns, and opportunities. One is the pipeline, two is the resources, and three is the need to innovate, and continue on.

So I want to start by focusing on Dr. Khan, there was something that you said, and—building into that pipeline, I think there are a few pieces to it that have been addressed, but the need not necessarily for everybody going into these fields, and to continue to grow, to have a 4 year or advanced degree. And I would love it if you, and then perhaps Dr. Gallagher and Dr. McNutt, could briefly speak to—there's a concept that I've talked to a lot of employers in my community, as well as education institutions, about stackable credentials, about helping individuals build the skills that they need to move into the workforce, to meet the workforce needs. Because many of the employers that I know, in Oklahoma and other places, are not finding people with the skills. And as we build into, not only the gap between men and women, but also there's a substantial gap in minority communities not coming into the STEM fields. If you could speak to the idea of stackable credentials using career techs, 2-year colleges, universities, things like that?

Dr. KHAN. I think you asked me to start. Let me—I've—we've talked about research universities as the engine for innovation, but at the—from an education point of view, we have an install base of community colleges across the Nation, and we have institutions that can offer 2-year degrees. And the question, from an industry perspective—and these are not research institutions, but educational institutions. And this is a question of and. It's not either/or, but we need to be able to think about how to do that.

There is a domino effect of not doing that, which was touched on earlier, which is these more rural communities start to lose their people into urban communities because that's where the jobs are, and that's where the facilities are. That has all sorts of other socioeconomic impacts to the communities that lose people versus the communities that are absorbing them. So I think our educational system has to be more diverse than simply deep academic institutions that are centers of excellence for research versus the large need for education and STEM talent in general.

Dr. GALLAGHER. So on the issue of credentials—so I don't think the hard part of credentialing is the—interestingly enough the stackability, or the—combining the training with, you know, what it takes. The community colleges, the educational enterprise of the United States, is pretty good at figuring out the training part. But a credential, to be useful, has to be recognized by the employers. And one of the breakdowns is that we, you know, it's—we have particular country—companies identify a credential that they would want, but it doesn't translate, so these credentials rarely have scale.

One of the real questions—I remember ANSI, which is the American National Standards Institute, which often registers many of these employer-generated credentials, the Microsoft engineering credential people are familiar with, things like that, but there are very few that you would recognize nationally, and one of the questions is who defines those from a, you know, from—that would be recognized in market. Interesting possibilities and, you know, it would have to be not companies. It could be collections of them, so these consortia, or sector-based, or trade organization-based. It could be labor, interestingly enough, that could play a role in defining some of these portable credentials that could be used.

I think once those requirements are generated, it's pretty easy to map out the educational strategy so that this goal of stackability and, you know, building on it is achievable.

Dr. MCNUTT. And I'll just briefly mention, there was a program at the National Science Foundation that was patterned after just what you are describing. It was called the Advanced Technical Education, the ATE program, where the idea was to provide a 2-year community college degree that would provide a living wage for a family of four for a single wage earner. And there were a number of ATEs that were set up, I remember, because I was involved in the MATE program that was out in California, the Marine Advanced Technical Education program, that was training people to work in the marine robotics industry. And—so it might be worth taking a look at those again, and finding out how they worked with industry on these credentials.

Ms. HORN. Thank you. I know my time is about up. I just want to say that I appreciate all of your testimony. I think this is an important and complex, but also it's a national security issue, as well as an issue of our competitiveness, and that it strikes me that everything that we're looking at has components for investment on cutting-edge research by the government, but also iterative research by industry, and then the pipeline, and many of these things have to be a partnership. So, thank you.

Chairwoman JOHNSON. Thank you very much. Mr. Cloud?

Mr. CLOUD. Thank you, Madam Chair, and thank you all for being here today. I really appreciate this topic. It's so important that we remain the world's leader in innovation. It's what we've seen in the last 100 years, with the United States leading the world, bringing an end to World War II, putting man on the moon, and us remaining that leader, it's certainly important that we continue to do that, and make that a priority as a Nation.

Now, the context that makes it challenging, of course, is that every year we have deficit spending. We're looking at $22 trillion of debt, which is also a national security issue, becoming such. So the question for me becomes how do we accomplish this? And there's a couple of areas of concern I want to point out. One is how do we ensure that the funding we do give toward science is going toward items of a national interest, and I'll name a couple. In the sense that there was a—$1.3 million given to the University of Washington to research whether koozies could keep drinks cold. There was another study for a half a million that had to do with shrimps walking on submerged water—underwater treadmills. And so how do we make sure that the money we do—we are allocating is going toward rightful purposes?

And then the other area I think that's a major concern is with China becoming such a major power play, they're not innovating, but they are stealing our innovation, to the tune of, some would say, $2 to $600 billion, which is actually more than we're spending in science right now. And so the picture I kind of have is that we have a bucket, we're being asked to kind of fill it up even more, but there's these holes in the bucket, and China actually has a bucket underneath it, and they're kind of taking it from us.

And so the questions I have would be what can we do to make sure that the funding we're getting is going toward national purposes, and then also what can we do to ensure, especially at the university level, where a lot of this theft is happening now, to ensure that we shore that up? And if I may, Madam Chair, I'd like to submit the IP Commission's 2019 Review.

Chairwoman JOHNSON. There are no objections.

Mr. CLOUD. Thank you. And, with that, I would hand it over to you all.

Dr. MCNUTT. I just want to make two quick comments. First of all, trying to decide what research is in the national interest, I think, is always going to be difficult to do. Let me just give you one quick example, the Cas9 bacteria, which everyone knows now because it's used in the CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) process to edit the genome. And whole new industries are growing up now with the potential to basically text edit genes for all sorts of purposes. That was done—discovering how that worked was research into obscure bacteria, and what they were doing, without any thought that it might someday be this incredible discovery, that it could actually edit genes in the way that it does.

And, on the second one, I'll say that the best way for technology transfer is actually not patents. It is the students and the post-docs walking out of the research labs, and going into industry. That is how ideas actually are most effectively transferred. It used to be that the students, no matter where they came from, went into our own industry. Now what's happening is they aren't staying here, they're going back to where they came from. So that's the problem we have now. If we were keeping the students here, we wouldn't be so worried about it.

Mr. CLOUD. I agree that that is a problem, but at the same time we have China hacking into our systems.

Dr. MCNUTT. Yes——

Mr. CLOUD. I think it was 27 universities recently. I mean, they're stealing everything from shipping secrets, to missile secrets, to fertilizer recipes so that they can have better production in agriculture. So they're catching us, and if—in my analogy, if we keep pouring money into this bucket without shoring up, I mean, we're in a sense funding their innovation as much as we are ours. So that's my concern.

Dr. GALLAGHER. I know—let me give a real quick answer. I think that your first point about the efficient allocation of Federal investments to make sure it's really on the top science comes down to a good identification of the areas of science. Remember how stimulative Federal investments are. They create new students, and new—so we have to make sure that the program calls that the agencies make are really clearly on areas of national priority need, because you're going to be creating new future capacity there.

I think that the good news is that the—by and large you're always going to see some outliers, and you're always going to see these kooky titles. The scientists don't do themselves any favors sometimes, but this is such an intensely competitive environment. These scientists are fighting for a very limited amount of funding. My experience has been that, you know, any outlier or poorly allocated research quickly doesn't get renewed or funded. And, of all the things to worry about, that efficiency is not the one that would be atop of my list.

I do think Dr. McNutt has pointed out something—I—look, we have to worry about our cybersecurity capabilities, and this problem with exfiltration of data and information, but the one I worry about the most is the exfiltration of talent, because, you know, the data is basically scientific or technical knowledge that we've already created. And it's true once that's gone, that's gone, but if the folks who are going to generate the next generation of talent aren't here, then we're not even—we won't have anything that's worth exfiltrating in the future. So I think that talent, making sure that these are knowledge-driven economies, we have the best talent here in this country is the competitive issue.

Dr. KHAN. Two quick comments to build on that. One is there's always this tension between focused, mission-driven research, whether it's, you know, sending a person to the moon, or—versus exploratory research. And I think we have to be careful the pendulum doesn't swing one way or the other, because the two are, at the end of the day, interdependent. And, as Dr. McNutt said, often research projects don't deliver in the area—well, quite often don't deliver in the areas that you think.

The second is, when we think about knowledge transfer in industry, and people that I hire as scientists, I'm not hiring them for the knowledge of the project they were working on, and I have thousands of scientists, I'm actually hiring them for their problem-solving skills that they learned in the laboratories of institutions funded by Dr. McNutt, or like Dr. Gallagher's. Once they come into that environment, they're going to face new problems to solve, but their skills were transferred.

You know, this transfer of knowledge, at the pace of change we're talking about, is relatively short lived. If you can't continue to iterate on it, it becomes obsolete. The estimate is about 50 percent of scientific knowledge is obsolete within about 5 years. And so it's old by the time—I mean, you finish your training, in my case, it's already old. So it is important to have that problem-solving approach.

Chairwoman JOHNSON. Thank you very much.

Mr. CLOUD. Thank you.

Chairwoman JOHNSON. Mr.—Ms. Wexton?

Ms. WEXTON. Thank you, Madam Chair, and thank you to the panel for coming and joining us today, and informing us on this important topic. As you are aware, we started 2019 in the midst of a 35-day partial government shutdown. NASA, the National Science Foundation, the National Institutes of Standards and Technology, the Department of the Interior, U.S. Department of Agriculture, and NOAA (National Oceanic and Atmospheric Administration) were just a few of the critical science agencies that were shuttered during this time. The National Science Foundation alone had almost 1,400 workers furloughed during the shutdown. And, because of the shutdown, hundreds of research proposals that were scheduled to be reviewed by the NSF for Federal funding had to be shelved. Others had to be pushed back. They also had to alter their merit review process in some cases, which had previously been called the gold standard, and the envy of the world. These are just a few examples of how the shutdown disrupted the work of our science agencies.

Dr. McNutt, can you talk about the impact of the shutdown on science and technology innovation, and on U.S. competitiveness more broadly?

Dr. MCNUTT. So we've actually been discussing doing a rigorous analysis of what the impact of the shutdown had on science and the scientific enterprise across the country, because we know for a fact that there were a number of important research projects, observational projects, field programs, that were interrupted, and had a very difficult time starting up again. There were many programs within the Federal agencies that suffered. Just as I said earlier today, that any kind of large swings in funding are difficult for science. The shutdown is the perfect example of a big swing that causes government labs across the country to shut down, and then have to spin up again, and that's very disruptive to the science. They try to keep the critical stuff going as much as they can, but it's still very difficult.

Ms. WEXTON. OK. And how has this affected our international scientific coordination and relationships with other nations?

Dr. MCNUTT. Well, we've always had trouble, as the U.S., with our annual funding program, being a good partner and remaining committed to our programs that we are involved in, in partnerships, and a shutdown is the worst thing that we can do, in terms of showing our commitment to partnerships, because no one can travel abroad. Sometimes people cancel their flights the very day of because they're not sure when a shutdown is coming. There might be a deal at the last minute, there might not, so it's very disruptive.

Ms. WEXTON. Thank you. Now, as Dr. McNutt noted in her testimony, national security is one component that depends on a strong and diverse STEM-educated workforce. Now, in Northern Virginia, which I represent, we have the Pentagon, as well as some of the world's top defense firms, who are tasked with coming up with technological solutions to a number of our greatest national security threats. They are reliant on a talent pipeline that we've heard—as we've heard today can't keep up with the demand for the highly skilled workforce, and they have an added hurdle of having new hires who may have to wait sometimes years for a security clearance.

To the panel, can you speak of some ways that the Federal Government can best partner with industry to ensure that we have the STEM workforce we need to meet our national security needs?

Dr. GALLAGHER. So the one—I'm not going to give you a complete answer, the but the one aspect of this that I think a lot about is that one part of that workforce, when you get to scientists and, you know, research intensive engineers, is that it takes so long to—remember, the training model is very in-depth. We put them into an environment where they do research at the cutting edge, and that's how they learn. It's an apprenticeship-based model. It takes many, many years, it's very expensive, and what you can't do is turn that capacity on or off.

So one of the things that, I think, from a national security perspective, is, and I think Dr. McNutt has talked about this, the signals that come from the government, through its funding, are one of the strongest signals in shaping demand and supply, because they go right to the universities. So our research dollars are not just doing research, they're training researchers. It doesn't handle swings up and down very well, which is one of the reasons, you know, the scientists are always claiming poverty when things—when even the growth rate isn't what they expected it to be.

So stability—and that's why I said whatever strategy we have from a science policy, there has to be a sustainable commitment to send those signals, you know, over a long period of time, because it takes 5 or 6 years, in many cases, to train a PhD If our—if we're changing our mind every year or two, then we're not going to see the effect that we want to see, and I think that goes to the poor allocation of those Federal investments.

Chairwoman JOHNSON. Thank you very much. Mr. Weber?

Mr. WEBER. Thank you, ma'am. Dr. Khan, I want to come to you. We heard today about the growing gap between the public and private R&D worlds here today, and I do want you to speak on this gap from the industry's perspective, and elaborate on the policies you believe to narrow that gap. But, before you do that, I want to make a couple of comments about the discussion we've had. We've talked about a path where we get people in STEM, where the colleges, whether they're junior colleges, which I graduated from, and the U of H, which is where I met my bride 42 years ago, at junior college, so I'm a big junior college fan. And then we go to U of H, but you graduate, and then you want industry to have a set of goals, I forget exactly how you all phrase that, to where we have a dual path going on here.

You've got universities, institutions of higher learning, education, call them what you will, are training up students so they can make that over into industry, and then industry has to be able to give them—you had a term for it. It wasn't certificate, it was something else, that they knew that they were on the right path to be able to work in that industry. So for R&D to work, I think we have to have an education system that has that aim in mind that's also STEM-oriented in some fashion, and is able to train up these scientists, if you want to call them that, and researchers, and you put them over into a system like you have, Dr. Khan, that you've been in. How do you get those goals into the university so that they can turn out students so that you've got good, productive scientists—researchers working for you?

Dr. KHAN. So I think Dr. Gallagher started this—addressing this in the need to create the right partnerships, coalitions, consortia, whatever term you want to use. Let me specifically address—and I always look at the young scientists that I hire into the organization, and then mentor, and we distinguish between technical skills which are needed for a specific task versus problem solving skills, which are learned.

Mr. WEBER. If you would hold just a second, you referred to the core competency in your—Dr. Gallagher, with—in your exchange with Mr. Gonzalez. Is that what you're referring to? The technical skills, the core competency?

Dr. GALLAGHER. That's correct.

Mr. WEBER. OK. Thank you. Go ahead, Doctor.

Dr. KHAN. So, as you can hear independently, we're aligned. When I take, and I look at a graduate coming out of a great institution, any of our institutions, I look—does that person have the technical skills to do the job today? And many times we actually have to provide them those technical skills in the early part of their career, when they come into industry.

Mr. WEBER. Why doesn't the college teach them those technical skills?

Dr. KHAN. Well, let me give you an example why that—why part of that is possible, but if you want to be—if you want to operate a manufacturing line, and you want to be the line engineer, it's unlikely that that full scale engineering line fits within an industry—within an academic environment. And, second, if we look at people management skills, how do you get your team of people to operate that line if you're that line engineer? So I can give you lots of examples where that apprenticeship part has to be picked up from—as the student arrives, or the graduate arrives, out of the academic institution into the work environment.

And I think any of us who made that transition, you learn a lot on the job. When I came out of medical school, that first year of internship was a heck of a learning curve, and I think that's true for—whether it's engineers, physicians, doesn't really matter. So that's one part. The key ingredient to success for our trainees is the problem solving skills, and STEM education in general allows them to focus, frame the problem, identify the resources needed, and then work on getting that problem solved. That skill starts from the first day they're in class in an academic institution. In fact, one thing I want to make a point, we all talked about the lack of people going into STEM, that shouldn't start at high school. We have to make STEM attractive right down to elementary school. We're losing so many young students because somehow we sort of have this—we communicate that this is going to be really tough, and we lose way too many students. So part of the problem is we're not getting enough very early in the pipeline.

Mr. WEBER. How did that get communicated to you?

Dr. KHAN. Multiple ways. I'm a father, I'm a grandfather, and I'm an employer and an educator.

Mr. WEBER. But you weren't a father and a grandfather when you started early in your education career. How did——

Dr. KHAN. I'm sorry, I misunderstood you.

Mr. WEBER. How did that get communicated to you?

Dr. KHAN. Because the teachers that I had—I was fortunate to have teachers that actually inspired that science and math was actually cool.

Mr. WEBER. How about your parents? They play a role?

Dr. KHAN. My dad was an engineer. It helped.

Mr. WEBER. All right. That is pretty informative. I appreciate that. I yield back, Madam Chair.

Chairwoman JOHNSON. Thank you very much. Ms. Bonamici?

Ms. BONAMICI. Thank you. This is a great discussion. Thank you to our witnesses. Dr. McNutt, you talked a couple times about risk taking, and we know it takes vision and persistence to conduct research in areas where the benefits are unknown, but we also know that that federally supported basic research has led to some pretty revolutionary advances in energy, and technology, and medicine, and more. And I'm sorry Representative Cloud left, but I wanted to invite him, and everyone here, to the Golden Goose Awards, which are held annually, where federally funded silly sounding research is acknowledged for the impact that it's actually made on society.

I'm also really glad that we're talking about higher education. I serve on the Education Committee as well, and Mr. Bera talked about the cost of higher education is—which is a real issue we hope to tackle this session, but I'm glad we're also talking about how we educate creative and critical thinkers. And, Dr. Khan, you mentioned flexible thinking and problem solving skills. We don't have enough conversations about how do we educate people to be creative problem solvers. And related is the lack of diversity in our workforce. We know that historically science and technology has not been especially inclusive of women and people of color, but we know that we'll get better decisions when we have diversity and various voices around the table.

It's also important that we're talking about not just getting women—girls interested, and women into STEM fields, but also keeping them there. Thank you, Dr. McNutt, for the National Academies report. I know Chair Johnson has a bill to implement many of the recommendations from that report. I hope we can get that done. I'm also the founder and the co-chair of the congressional STEAM Caucus. We have had conversations about, and actually gotten some policy passed, in integrating arts and design into STEM learning, which we've seen as very successful in addressing the lack of diversity, because oftentimes kids, when they're going through school, they think they're good at English and art, and they're told, you have to choose, you can't do both. You can either be the English and art kid, or you can be the science and math. So in schools that are integrating arts and design into STEM learning, it's helping to diversify the students interested in STEM, but is also going to result in a more innovative and curious workforce because, when the whole brain is educated, that's what happens with the mind.

Dr. McNutt, confronting climate change is one of the most significant issues of our time. I thank you for the Academies review of the draft of the—for the National Climate Assessment. It's going to require innovation, leadership, risk taking, responsible use of the vast resources in our country. You talk about how federally funded research comprises approximately a quarter of total research and development expenditures. You talk about how we'd be served better through robust Federal support. At the same time, we've seen this Administration propose drastic cuts to Federal R&D and Federal science agencies. So why are stronger Federal investments in R&D important for demonstrating our Nation's leadership in tackling important issues like global climate change?

Dr. MCNUTT. So with specific reference to global climate change, we—the scientific community is clearly united in its understanding that climate change is happening, and that it's anthropogenic, but there are many things about climate change that still need to be understood better so that we can make wise choices about how to prioritize our response. Because we know that the clock is ticking, and it's ticking down on the time that we have to make the right investments to respond quickly enough to actually do the triage that we're going to need to do if we're going to get to the other side of this in some way that is beneficial to society and our way of life. So understanding whether the biggest threats are going to be to agriculture, are the biggest threats going to be to the wild places, are they going to be to the coastal communities, these are all things that we have to put more of a fine point on, and make better predictions that are scaled down to the actual sectors and the actual geography.

Ms. BONAMICI. I look forward to working with you on that. And, quickly, Representative Wexton asked about the shutdown and its effect. Dr. Gallagher, when we see the budget cuts, the shutdown that Representative Wexton mentioned, the immigration issues, how is this affecting our ability to recruit good people, and keep them here, and keep them in—as Federal employees?

Dr. GALLAGHER. Well, I think that, anecdotally, I see evidence of people leaving Federal Government for other approaches because of the high uncertainty in those roles. That's selfishly been good for employers like the University of Pittsburgh, who are looking for talent, but I don't think that's good. Some of those Federal capabilities would be incredibly difficult to rebuild, so I hope it's not a very deep loss. And, anecdotally, we've seen the effect of uncertainty even at the university. We see it in enrollment rates, in visiting faculty coming, in collaborative research, in some of the uncertainty around grants, the willingness of some of our, let's say, international partners to begin looking at—possibly looking at, let's say, a joint grant. When the U.S. Government sort of, you know, does this, it sends a signal that maybe we're not a reliable partner.

But I do think we won't know the full impact of that, both the direct effect of the shutdown, and that uncertainty effect, or opportunity cost, of the shutdown probably for several years, and that's really the tragedy of these things, is that it kind of leaves a void in the system that you don't really see it play out for some time.

Ms. BONAMICI. Thank you. I yield back. Thank you, Madam Chair.

Chairwoman JOHNSON. Thank you very much. Mr. Baird?

Mr. BAIRD. Thank you, Madam Chair, and thank you, experts, for being here, and the testimony, the discussion we're having today. You know, I'm excited about what's happening in agriculture. I mean, the STEM demand there is rapidly growing. And, as a result of that, we're able to produce—and if we're going to feed 50 billion people here in some time, that's certainly important. And—then I just wanted to share with you, because all of you had mentioned various aspects of this, but I—I'm a kind of a practical individual, and I know when I started my PhD program, it went back to when I was in high school, even prior to that. And so you mentioned earlier attraction, down to K-12. But I had teachers who recognized some skills, some aspect that I might have, and they thought—and they encouraged me, and even had that in high school. And so my point here is—being that—then as I got to college, and managed to get into some of the courses, then I got interested, and I became increasingly interested, and that ended up resulting in the PhD.

So my point is a couple of these. One, I'd like for you to comment on how we encourage the education program to stimulate these young people like I'm talking about, and then the other thing that you might also comment on, I really like the idea of the community colleges. It gives some of these individuals the opportunity to get a flavor for that kind of education without investing a lot of money, and then it also gives them the opportunity to decide, you know, what kind of engineer we want, or what kind of a degree we want. It gives them the exposure to that without having to make a lot of investment. So I guess my two questions are, how do we encourage the education system to do what I mentioned, and second the community college idea?

Dr. MCNUTT. If I can make just two quick comments, the reason I'm a scientist today, and I know that this is a fact, is I went to a girls' school my entire life, so I didn't encounter anyone who told me that I couldn't do math and science until I got to college, and by that time I was so sure I was going to be a scientist that I said to that professor, well, what's wrong with you, if you don't think I can be a scientist? And—so—but the girls' school I went to, it's not a girls' school anymore.

So this is why I think, for attracting minorities into the sciences, I'm really keen on supporting the historically black colleges and universities. I think that they will also provide that safe place for minority students to get involved in science and engineering without anyone telling them they're not supposed to do that, and their professors all look like them, and they can tell them, yes, you should be doing this, it's good for you.

Dr. GALLAGHER. Let me add an optimistic note. So we tend to focus, when we see these gaps and these crises, that, you know, we have to reinvent our system of higher education, we have to look at how we do better. And, look, some of this is great, because we're going to innovate some new approaches. But we're stressed about this because the global competition's gotten really tight. And the reason it's tight is those countries are basically copying the U.S.

system. So I just want to point out, you know, they're running up against us simply because they're doing exactly what we're doing, and they're trying to do everything the Americans do. I think that means we have to, you know, we have to get a little smarter.

I—the one thing I was going to—just an observation, you know, I mentioned early on Sputnik. You know, one of the big moments in U.S. history when, as a country, we really focused on the role of science, and people getting excited, and there was remarkable investment that was made, but there was also a remarkable amount of passion and belief that came. That wasn't just because science was cool. I mean, a lot of us were excited because we either saw somebody in our lives who was a scientist, or we just thought it was really interesting, but there was a national call to serve, and it was a way where people believed they could contribute to their country.

And I always go back to, you know, when I was at NIST, we had five of our scientists win Nobel Prizes, which was remarkable. It's not that big of an agency, and—but the untold story was all five of them stayed there. They could've quadrupled their salary going somewhere else. And I remember talking to them and asking, why did you stay? And they said, there's great problems, that's the scientist in them, great colleagues, and it was a chance to make a difference and serve our country. And I think that's something that our science policy can create that almost no one else can, is how is this vital to our national interests? How—because people want to make a difference.

Dr. KHAN. There's a common theme in what you've just heard, which is experiential learning. I think, if you actually expose a young person to the coolness of solving problems, regardless which they are, then all the other hard stuff are tools that they learn in order to do the cool stuff. But if the primary mission becomes, you're going to actually be learning all this hard stuff for the sake of learning it, I don't know anybody, really, who wants to do it.

And I think, if I was to rethink the education, one of the things that I think we do much better in industry is we take these young graduates, and we put them onto real problems, and that becomes aspirational. Whether it's putting a man on the moon, or, in my current job, feeding the world's population of seven billion people, with a billion hungry, in a sustainable manner, so it doesn't take away from the next generation, or my new job, which is how do we make the billion plus people that are aging to stay healthy and functional in society, rather than being a burden on society? That problem will attract very bright minds, and I think we have to think experiential, goal-oriented learning.

Chairwoman JOHNSON. Thank you very much. Ms. Stevens?

Ms. STEVENS. Well, thank you so much. It's a real privilege to be in the room with you, Dr. Gallagher. We share both having served in the Obama Administration. I've long admired your leadership and work, particularly your leadership of NIST during the *Recovery Act* period when I was working at the Treasury Department for the President's Senior Counselor for Manufacturing Policy, when we just started to develop those manufacturing institutes that my colleague, Conor—Representative Lamb mentioned.

Dr. Gallagher, if you don't mind, could you just indulge me in listing off some of the Federal agencies that fund or support U.S. leadership in science and technology?

Dr. GALLAGHER. That's pretty broad. It's—we're quickly getting to the point where—which ones don't? But the ones that are very university facing have the large extramural programs, so clearly our agricultural department, the National Science Foundation, the Department of Energy, the Department of Defense. NIST has a small program. USGS has a program. I—there—NIH. Yes, how could somebody from Pitt forget NIH? So it's really becoming ubiquitous, and I think that's because every single mission in the government is becoming quite centered around know-how, and knowledge, and science, and technology.

Ms. STEVENS. So would it be fair to say that the Department of Energy (DOE) has played a pretty prominent role in propagating 3D printing? Would it be fair to say that the Defense Advanced Research Projects Agency has played a pretty big role in putting forward the initial research that led to the development of the Internet that NASA, NSF, and DOE also played a role in proliferating the usage of the Internet?

Dr. GALLAGHER. Without question.

Ms. STEVENS. And would it be fair to say that the—to the best of your knowledge that the top five performing stocks by market capitalization in this country are Apple, Amazon, Microsoft, Alphabet, Google, and Facebook? Yes. So, Dr. McNutt, are—based on some of your global leadership, and work internationally, are you aware of any conversations or debates in Germany, South Korea, China, in which their governments debate the merit of investing in science and technology broadly?

Dr. MCNUTT. No.

Ms. STEVENS. Thank you. And, Dr. Khan, if the U.S. Government were to stop investing in basic research, what organizations would fill the capacity of this role?

Dr. KHAN. At present time we don't have an alternative.

Ms. STEVENS. Thank you. I yield back the remainder of my time.

Chairwoman JOHNSON. Thank you very much. Mr. Balderson?

Mr. BALDERSON. Thank you, Madam Chair, and thank you, panel, for being here. Couple questions, and Dr. Khan, you're going to be my last one, so just heads up, because what you just said was probably one of the best things that's been said here today. It was about giving them the environment of what's out there, other than just sitting behind a desk the whole time and being educated. But—hands-on is, I guess, the word for it.

I'm going to follow up with my colleague from Northeast Ohio. I'm from Ohio also. I represent a pretty unique district. It's urban, suburban, and it's rural. My home county is Muskingum County, and it's in Appalachia. I actually call it the Shaker Heights of Appalachia. It's the largest populated county in the State—or the region of Appalachia. But going back to, you know, the need that's there, and getting left behind, you know, those folks feel like they're being left behind. It's just there's no interaction there. Right now, in that region of the State of Ohio, right now there's some negotiation going on with the petrochemical plant that's going to provide 4 to 6,000 construction jobs. It's a company called PTT. It's part of the shale play that's happening there. Shale is right across the river, in Pennsylvania.

But my concern is—and it's everybody's concern, and we have community colleges, and we have 4-year colleges working, trying to get this figured out, this workforce demand. What can we do to ensure that these rural and more lower urban communities get the same access to this? And emphasize a little bit more, I mean, what you said for Representative Gonzalez. I just—I want to push a little bit more for ideas.

Dr. GALLAGHER. So, as I said, one of the concerns I've always had is that we get mesmerized by just one segment of the—let's call it the innovation ecosystem that needs to happen. So, take your example, where you're looking at the shale energy, and looking now at either petrochemical, or crackers, and looking at polyethylene production. So that's great. I mean, that is a natural advantage for that region in the sense of you have a low-cost energy infrastructure, and some assets that nobody else has. It's necessary, but it's not sufficient. I mean, that can be an entirely extractive economy. You can take that stuff out, and take it somewhere else, to do what industry would call the value add.

And so the goal really has to be—and I think this is actually something we can do much better. We have focused on the jazzy part of this, you know, the high-tech company, and the idea—you think about the Amazon discussion in New York. You know, the reason there was this big pushback is I think people are skeptical that that one employer, that one piece of technology, will spill over and create an economic activity that benefits the region.

In manufacturing, the regional and—the rural and suburban areas, including through Ohio and Western Pennsylvania, they were drivers of the middle class employment wave, and that happened largely not at the very top research intensive OEMs (original equipment manufacturers), or at the base, it happened through the supply chain. The U.S. supply chain, I believe, is really in trouble right now. It's not seeing the technology benefits that the large companies are investing, and you can't just assume it's going to come up from those base activities.

So one of the reasons I'm excited about the manufacturing institutes is that you're pulling together a sector, that they worked because you've got essentially a consortia of like-minded companies that share something. That consortia can take ownership over that supply chain problem, and look at making sure that those investments, that capital, are going into those plants. That's going to—that's what drives the employment. That's what's going to shape the demand for community college and others to step up and try to, you know, retrain people to take those jobs. This is an area that, you know, has a habit of working hard, and knowing what these jobs are like. You just need to be able to match up, and make sure that these technology innovations—we don't just assume it'll happen, but we do it with some intent.

Mr. BALDERSON. OK. All right. Thank you. Dr. Khan, as I said, I'll wrap up with a question to you. What you did is something that I've done in the past, and that's—take any business owner who is personal friend, and, you know, telling me how he can't find the workforce out there, young kids. And I, you know, I'd make the suggestion, have you ever reached out to a vocational school, have you done this, or a community school? Well, no, I haven't. I didn't know I could. I mean, people say you can't have kids come into the workforce, but, you know, to me, and my own background, I wanted to do what I was working for. I wanted to actually do a touch and feel and do that.

And I had the vocational school reach out, we picked six kids, and three of kids ended up getting jobs at this facility. So I couldn't agree with you more, as far as getting them out there. Is PepsiCo.—I mean, do they take that real world experience, and take them out there, and let them see what the end result's going to be?

Dr. KHAN. Sorry. We expose them as early as—even before they start college. We'll take high school students, and give them—because one of the things I'm competing for this talent is with these high visibility, sexy industries, and then you say, hey, how about food and beverage production and agriculture? It's not as sexy as working for the latest AI company, but yet the impact on the world, and the impact on our country, is profound. It's—every one of us consumes foods and beverages every day, and so getting them exposed is part of that.

But I want to just also emphasize one other thing. Manufacturing, as we all know, is going through a transformation, and, with that, as our efficiency and productivity is going up, it is uncoupled from job creation. Let's not confuse that. Because as automation has come in, as AI has come in, we can still have that rural plant, but it's not going to have as many employees, and in fact it's a log scale difference. Where we need to train is the human interface, where machines aren't going to do—in order for us to remain competitive we need—so most of the jobs that are coming are actually coming at either the human/machine interface, or the human/human interface. And a lot of our existing employees from the past, in our education system, was training people to do jobs that actually are becoming obsolete, but being replaced by different jobs.

So I want to really still emphasize that we have to think about retraining, and retraining a whole different skillset. That was not the case when I was coming out of high school and college. It was a different generation.

Chairwoman JOHNSON. Thank you very much.

Mr. BALDERSON. Thank you.

Chairwoman JOHNSON. Mr. Tonko? I'm sorry, Mr. Casten?

Mr. CASTEN. Thank you, Mr. Tonko. Thank you, Madam Chair. Thank you to the panel. Dr. Khan, I'm sitting here chuckling at your comment about how none of us are actually doing the job we trained for. Twenty-five years ago I was getting a master's degree in biochemical engineering, and I just want to say to the millions of people watching us on C-SPAN right now that you are, you know, sitting there doing computational thermodynamics and working on fermenters, you are transparently trying to primary me next season, I know it.

On a more serious note, one of the things that has just sort of shocked me, you know, being a little bit away from that field now, I went down and toured Argon National Lab, that's just south of my district in Illinois, and their photon beam accelerator, and realizing that the way we do science has changed so much. You know, I used to take all day to do an experiment, which meant that I had to very carefully shepherd my time to design a careful experiment. And now, you know, it's orders of magnitude. You've got 96 wells at a time. It takes minutes. And I was sort of saying to the scientists there that you've changed the way that this works, because now you do experiments and work backward to find out what's the hypothesis of why that well lit up, as opposed to do I have a hypothesis in advance?

And that's not unique to fields that I have any experience in, but it does strike me that the—we're not paced by our ability to create data, we're paced by our ability to process and understand that data. And so my question for any, or all, of you is what are we doing, or could we be doing more of, to maintain a lead in the kind of computational science and engineering that is driving so many of these fields, and is growing it at rates that are hard for me to fathom?

Dr. KHAN. Can I—I'm going to be provocative to my scientific colleagues. The education that most of us, as scientists, historically received is somewhat—how to condense a problem to the minimal number of variables, and solve for that one variable. And the ideal experiment, regardless of discipline, was you could control every variable, except for the one that you wanted to study. That's about as non-real world as it gets. And that was done because that was the only way we, as humans, could understand the results of that experiment.

We now live in a world with computational capabilities, and some of the—and, in fact, into the future, when we get into quantum computing, which your former institution is driving, we're going to be—or these machines are going to be designing experiments that they can interpret for us. We can't even start to imagine the number of variables in that real world environment. So if you look at that, then are we really now training and thinking about these real-world global problems with scientific rigor and approach, which is very different than the regressional approach that we were all educated in? And I think all three of us are of that generation.

Dr. MCNUTT. I'll just add that one of the hottest areas right now, where students are being snapped out of universities, is any student who is very well versed in dealing with big data, with statistics, with complex systems, and with complex modeling. And it almost doesn't matter what they were trained on. If they are comfortable doing that, they are in demand. And we have undertrained in the past in the statistical area and the complex systems.

Mr. CASTEN. Yes, I can vouch. I sat for a long time on the advisory board of Dartmouth College's engineering school, where I went, and you can tell what the sexy degrees are. I want to just, with the little bit of time I have left, and—pick up on a bigger issue, and sort of to some points that Dr. Gallagher raised in your written testimony. All of you, in some capacity, have mentioned this shift, proportional shift, away from publicly funded research to privately funded research, and the difference between basic and implied science that that implies.

I want to talk about how we think about that with international IP, China specifically, but we, up here on this panel, have certain jurisdictional controls to protect our private data when it's produced in public entities or on our shores. As we get to a world where research is being done by the private sector, by increasingly transnational corporations, I'm not sure we have the tools, and I just welcome your thoughts, on how we actually protect national IP in a world of global information.

Dr. GALLAGHER. Well, I, you know, my view, and I think this was the case on the cyber commission, we were talking about this, one of the reasons that technology is so disruptive is that it was intrinsically global. So it was moving information around, you know, beyond borders, and moving into realms where there's no law enforcement reciprocity. These issues of IP spillage have to do with the fact that they're difficult to enforce, that international standards of behavior are not uniform or applicable——

Dr. MCNUTT. You know, our ethics.

Dr. GALLAGHER [continuing]. Ethics. I think that the only way you have a—look, we connected every person on the planet with a—with computing capability and a light speed communication tool, and we're—now we're grappling with the implications of that. And some of that will have to be done through the hard work of global engagement, and hammering out those kind of international norms, that kind of law enforcement structure, those kind of rules of the road.

The flipside is, I think, you know, the local part. What is—until that happens, when there's some of this Wild West happening there, how do we continue to protect ourselves the best we can against some of the most damaging and adverse impacts, and that's where companies and individuals, the government, are looking at trying to protect identifiable critical assets. But until we tackle the broader issue, I think this is always going to feel like we have it inside out.

Mr. CASTEN. Thank you.

Chairwoman JOHNSON. Thank you very much. Now, Mr. Tonko.

Mr. TONKO. Thank you, Chairwoman. Thank you to all of our witnesses for joining us today to discuss this very important topic. As Dr. McNutt highlighted in her testimony, it has been more than 15 years since the National Academy has made clear that America's commitment to research is critical to our ability to lead and compete in science and technology. Unfortunately, over the last decade, many of America's leaders, possibly including Members here today, failed to heed that advice and keep pace with other nations.

As the rest of the world continues to take extraordinary steps to drive innovation in their own economies, the previous Republican majority in Congress put America on the wrong track, in my opinion, with major areas of vital research not adequately funded. It is time to correct our course and restore our commitment to invest in innovation, in research, in development, advanced manufacturing, and certainly in our STEM workforce. In particular, we have an opportunity to address the climate crisis through the United States leadership, and a commitment to research and development of the next generation of climate mitigation and prevention tools.

So, Dr. McNutt, you urged that we, and I quote, "simply cannot afford to let the United States leadership in science slip away." That's your quote. What data have been looked at by the Academies to determine that we are already falling behind?

Dr. MCNUTT. So the data that's most complete at this point is the data from the National Science Foundation, the science and technology indicators. As I said in my opening statement, we've got leading indicators and lagging indicators. The lagging indicators, we have to be careful about putting too much weight on those because, by the time that we start slipping in them, it's too late. We've already lost.

What I think is the most important leading indicator is to what extent do the very top students, anywhere in the world, want to come here to get their degree, because we have the best university system, and we have the best innovation system that they want to enter because it is the very best opportunity for them to pursue their careers? And we're already seeing a falling off in applications for graduate school from the deans, and we're already seeing that their opportunities are better elsewhere.

Mr. TONKO. Thank you. And then federally funded research through the SBIR (Small Business Innovation Research) program generated some two-thirds of the components inside the smartphones we're all carrying today. And U.S. research has launched the Internet, and transformed clean energy technologies, and catapulted numerous other thriving American industries. Why, in your opinion, is Federal funding such an important driver for research to create world changing technology?

Dr. GALLAGHER. Well, one of the main reasons is it can take risks that the private sector simply wouldn't take yet. So by—that's a classic market failure argument, but they can take a very high risk, but very high payoff, chance, and look at that—at a problem in a way that I think would be very difficult for a company to justify doing.

Dr. KHAN. Can I just compliment Dr. Gallagher's comment on that, and maybe add to it, because it isn't just the risk. Industry, and no one company, has the resources and the talent pool that the collective workforce of the academic institutions has. And so the mobility of knowledge that occurs within—between academic institutions, the collaboration that occurs, allows a much broader and deeper workforce. That won't happen in industry. I don't care how big a company is, it doesn't have the resources of a complete research university faculty.

Mr. TONKO. Um-hum.

Dr. KHAN. And—so funding that allows not only the risk-taking, but actually the brainpower to solve the problems in its components. What industry does very well is integrate those components. I think you gave a great example. The components of that smartphone were invented by government-funded research, but that government-funded research didn't develop the phone. That was the integration. And what industry does very well, and the best in the world in—is the U.S., is that integration. That partnership, in my mind, is component/integration. Together it's invention/innovation, as I described earlier.

Mr. TONKO. If I might just get one more quick question in, Chairwoman? Can you talk, Dr. McNutt, about how the Academies view the intersection of research and climate change?

Dr. MCNUTT. Yes. So the Academies view is that research is essential so that we can make predictions about our future. And, right now, we can do a certain amount of attribution for the current state, but let's ask a simple question about just investment. Without further investment in understanding our climate future, more modeling, more understanding of how systems work, I couldn't confidently answer the question for you whether the current limited crops we have that produce—the 75 crops that basically feed the world, whether in 50 years those crops, in their present form, will still all be viable.

Mr. TONKO. Thank you. Well, as the recently appointed Chair of the Environment and Climate Change Subcommittee, we look forward to working with your organizations to see what we can produce, in terms of research. So, thank you. With that, I yield back, and thank you, Madam Chair.

Chairwoman JOHNSON. Let me thank you, Dr. McNutt, Dr. Gallagher, and Dr. Khan. I'm so grateful, we are grateful, that you've come and spent your afternoon with your phenomenal knowledge that you've shared with us. We appreciate you being here.

And I want to say that the record will remain open for 2 weeks for additional statements from the Members, or any additional questions to the Committee that they might ask you. So we thank you very much, and the Committee hearing is concluded.

[Whereupon, at 4:57 p.m., the Committee was adjourned.]

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Marcia McNutt

NATIONAL ACADEMY OF SCIENCES

Office of the President

U.S. House of Representatives, Committee on Science, Space and Technology hearing "Maintaining U.S. Leadership in Science and Technology"

Responses by Dr. Marcia McNutt, President of the National Academy of Sciences, to Questions submitted for the Record

Question submitted by Congresswoman Mikie Sherrill

I have several questions for the record to address strengthening quantum research, both for defense applications and U.S. economic competitiveness.

1. *What are the most urgent/promising lines of research in quantum both for defense-related applications as well as those applications that will have direct impact on U/S/ economic competitiveness?*

In January of this year, a committee of the National Academies of Sciences, Engineering and Medicine released an important study, "Quantum Computing: Progress and Prospects"[1], which assessed the nascent field of quantum information science and technology (QIST). The report describes three broad categories of activity in the field: quantum sensing and metrology; quantum computing and simulation; and, quantum communications and networking[2].

The most mature technologies stem from R&D in *quantum sensing and metrology*, where quantum systems are engineered to be very sensitive to changes to their physical environment. Typically based upon atomic or optical systems, these have potential for much more precise measurements than afforded by currently deployed technologies.

Research in *quantum computing and simulation* could potentially lead to systems that perform some computations exponentially faster than the computers we have today, including quantum computation[3] that would break the encryption that currently protects digital information and communications. While only small-scale or special-purpose systems exist today, in principle, large-scale, universal quantum computers could be built. However, significant technical advances would be necessary before such systems could be achieved. A quantum computer capable of cracking today's encryption is highly unlikely to be built within the next ten years, and breaking cryptography may not be the primary driver of developing quantum computing technologies. Even so, pressing ahead with the ongoing work to switch encryption algorithms to quantum-safe methods is of critical importance, as transitioning between cryptosystems is a long process.

[1] National Academies of Sciences, Engineering, and Medicine. 2019. *Quantum Computing: Progress and Prospects*. The National Academies Press, Washington, DC. doi: https://doi.org/10.17226/25196.

[2] A recent report from the Science and Technology Policy Institute (STPI)," Assessment of the Future Economic Impact of Quantum Information Science", includes estimates of market value for these categories: https://www.ida.org/idamedia/Corporate/Files/Publications/STPIPubs/2017/P-8567.pdf

[3] In particular, by deploying Shor's algorithm, a theoretical discovery that stimulated much early activity in the field.

The potential of quantum computing and simulation to accelerate even part of a complicated computation means that quantum computing could prove extremely valuable at some point in the future. Work to develop algorithms and applications for quantum computers are important ongoing areas of research and, while it is not currently clear what algorithms will be most important, or for what applications, the areas of quantum chemistry and machine learning are often raised as possibilities. Research into practical applications of near-term quantum computers is an area of immediate urgency for the field, and expected to affect the timeframes for long-term progress. Furthermore, in the near-term, quantum computers are expected to be "noisy" (error-prone) and relatively small. So, research into error correction, error mitigation, and scale-up of today's devices is also of critical importance.

R&D in *quantum communication* focuses on the transport or exchange of information by encoding it into a quantum system, and includes the field of quantum cryptography. Some quantum communication technologies are commercially available or have been deployed at a pilot-scale. However, it remains unclear what the most valuable use-cases will be, and whether they will outperform existing alternatives.

All areas of quantum information science and technology are based upon the same principles: control of the fundamental quantum-mechanical properties of physical matter. The boundaries between the subfields are not always clear-cut, and research in one area may be valuable for making progress in another. In addition, progress in these fields has great potential for stimulating new approaches to science and technology in the non-quantum regime. Indeed, progress in developing quantum algorithms for quantum computers has already directly stimulated the development of new, more efficient non-quantum algorithms, effectively spurring new progress in non-quantum (sometimes referred to as "classical") computing.

Today's work to build quantum information and communication technologies requires unprecedented control of physical systems, and R&D in these fields is at the cutting edge of human knowledge and capabilities. As a result, it is not possible to predict fully what new discoveries or understandings will emerge from this research– or what technologies could follow. Ensuring the United States' ability to benefit from these fields requires not only pursuit of technology development, but also sustained support for foundational research (including in quantum physics and quantum chemistry) that advances our technical capabilities, cultivates human talent and innovation in these fields, and expands the boundaries of human knowledge.

2. *What are the existing U.S. strengths and capabilities in quantum research that should be exploited?*

The U.S. has historically been a top producer of QIST R&D, with many researchers participating in an open and vibrant ecosystem. As of 2016 – the latest data available to the Academies study committee - the US has been the top net producer of publications in quantum computing and algorithms, quantum sensing and metrology, and quantum communications.[4] The U.S. has also been a leader in foundational research, with a strong academic enterprise. Today, there are multiple U.S.-based startup companies and major technology corporations with significant investments in R&D in quantum computing and other quantum technologies.

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[4] According to a 2018 bibliometric analysis of publicly available publications performed by Jacob Farinholt, Research Scientist at the Applied Mathematics & Data Analytics Group, Strategic & Computing Systems Department, Naval Surface Warfare Center, Dahlgren Division. This report was provided to the Academies' study Committee on Technical Assessment of the Feasibility and Implications of Quantum Computing.

Recent years have seen a surge of interest in QIST; current levels of enthusiasm could be harnessed to bring together students and experts from a range of traditional disciplines, to shed new light on existing problems, push the frontiers of knowledge in new directions, and provide inter- and multi-disciplinary educational and training experiences. Benefiting from advances in QIST will require a prepared and vibrant U.S. workforce.

At the same time, it is important to maintain a long-term, strategic view, and consider sustainable multi-lateral engagement efforts that can be maintained productively and adapt as the landscape advances and evolves.

3. *In what areas is the U.S. lagging behind other countries in quantum research—both in pure and applied research?*

While the U.S. has long been a leader in the QIST fields, R&D efforts around the world have grown significantly in recent years. Several countries have made significant commitments to support R&D in this area, and the United States recently increased its commitment to R&D by launching the National Quantum Initiative in December of 2018. Given these significant efforts world-wide, sustained U.S. support is critical if the U.S. wants to maintain its leadership position in QIST — or even be a fast-follower.

Questions submitted by Congressman Bill Posey

1. NASA has a storied history of heroic astronauts and amazing feats that all rest on science and engineering. Along the way people realized that our space program often gives rise to science and technology and products that finds their way into our everyday lives. We call these products "spinoffs" and some of them .. .like the chips in our phone cameras ... have become everyday parts of our lives. NASA publishes an annual magazine called "Spinoff' that has documented over 2000 contributions of NASA research to other fields. Are other R&D organizations celebrating "spinoffs?" Do panel members believe that other federal R&D activities could help the cause of science by doing what NASA has done with "Spinoff' and its technology transfer initiatives?

Discoveries in government sponsored research have helped the private sector stimulate new businesses, jobs, sustainable economic development, and economic prosperity. Some measures of federal agency technology advances from 1996 to 2015 show over $1 trillion in economic growth.[5] Sharing federal laboratories' discoveries through open sources of information ensures America's leadership in cutting-edge technologies at the frontiers of knowledge in areas such as artificial intelligence, 3D printing, rocket technologies, and quantum computing.

Nearly 40 years ago, Congress assigned the federal government the continuing responsibility to appropriately transfer federally-originated technology to state and local governments and the private sector. Across the federal R&D landscape, agencies have taken to two distinct avenues: communicating the impact federal research has on American's everyday life, and making a clear pathway for entrepreneurs to access inventions developed with taxpayer funding.

[5] NIST Special Publication 1234 "Return on Investment Initiative for Unleashing American Innovation," December 2018, https://doi.org/10.6028/NIST.SP.1234

As you note, the NASA Technology Transfer Program has connected NASA resources to private industry, highlighting the commercial products in a publication called "Spinoffs." To achieve one of its chartered purposes of "the preservation of the role of the United States as a leader in aeronautical and space science and technology," NASA has undertaken extensive outreach to encourage technology transfer.

Each year, the Federal government invests approximately $150 billion in R&D.[6] Each of the major federal R&D players supports technology transfer in ways similar to NASA, but matching the diverse needs of commercial interests in their fields. For instance, DOD provides for domestic technology transfer at DoD laboratories, effectively identifying transferable technology and establishing internal controls and procedures to prevent improper disclosure of patentable technologies. Whether it is working with entrepreneurs interested in commercializing technology or collaborating with academicians on warfighter-driven technological investigations, the DoD technology programs encourage collaborations.

Looking at another federal agency, the USDA broadly defines technology transfer as the adoption of research outcomes for public benefit, focusing on delivering solutions to the people of the United States. Each year, the USDA issues an annual report focusing on a variety of mechanisms and metrics to assess their technology transfer successes, including public release of information, tools and solutions, adoption of research outcomes through collaborative or formal agreements, and licensing of intellectual property.

2. We rely on science to produce knowledge that fuels innovation in our economy. Knowledge is an interesting economic good. Once knowledge has been produced, the cost of the next person using it is about zero. It would seem inefficient not to let everyone benefit from knowledge once it's been produced. Yet we understand that without incentives to produce knowledge, much of it simply wouldn't be produced. To provide these incentives we have our intellectual property rights system and patents. We're here today talking about the role of government in sustaining scientific leadership and one of the tools to do that is intellectual property. Does the panel believe that we are striking the right balance with our intellectual property system and providing enough incentives to sustain our leadership in science?

This is, and will likely always be, a critical question facing the unique and ever-evolving innovation enterprise in the U.S. The National Academies has released a number of studies looking at intellectual property, the patent system, and the copyright system. Some of the recommendations in its 2004 study, "A Patent System for the 21st Century[7]", were included in the America Competes Act of 2010. The most recent National Academies study, "Managing University Intellectual Property in the Public Interest[8]", released in 2011, touches on a number of issues related to federally funded research and how to ensure that there is wide dissemination of university-generated technology. That report made a number of recommendations to improve the transition of knowledge from the university to the broader public.

Since 2011, there have been a number of new developments in the knowledge-based economy, including a surge in digital technologies. A number of court cases, including the Supreme Court's decision against the Alice Corporation, have raised issues around the question of what subjects are patentable or what is new or useful, and have raised questions about how the patent system is currently working. At the present

[6] https://www.federalregister.gov/d/2018-09182/p-4

[7] National Academies of Sciences, Engineering, and Medicine.2004. *A Patent System for the 21st Century*. The National Academies Press, Washington, DC. https://www.nap.edu/catalog/10976/a-patent-system-for-the-21st-century

[8] National Academies of Sciences, Engineering, and Medicine.2011. *Managing University Intellectual Property in the Public Interest*. The National Academies Press, Washington, DC. https://www.nap.edu/catalog/13001/managing-university-intellectual-property-in-the-public-interest

time, the National Academies is launching a study into improving commercialization of federally funded digital IP, only some of which are afforded protection by copyright. In addition, the National Academies has been having discussions about the Inter Partes Review process as well as discussions about the relationship between patents, drug prices, and innovation. All of these issues need further exploration by expert committees that include scientists, legal scholars, and economists. And, as our legal system is always evolving to match the rapid pace of innovation, these issues will need to be continually reassessed.

3. *What is the most important thing Congress can do to sustain our leadership in science?*

The United States cedes leadership when we do not attract the full diversity of the best and brightest minds - from the U.S. and across the globe - with robust and reliable funding, world class facilities, the freedom to pursue high-risk high-reward research, and the promise of rewarding careers in the U.S. As one prominent Chinese entrepreneur said to me recently, the advantage of the US scientific system is that it fields the entire "Olympic team," whereas other nations inadvertently filter for single skill set.

Throughout the range of S&T domains, international competition is intense, and with our allies and adversaries alike. Policymakers in the U.S. face difficult decisions in allocating resources and setting priorities, and the considerations are complex in defining the appropriate role of government funding across the innovation spectrum. However, we must keep in mind that leaders in other nations are not spending their time debating many of these issues. They are examining every metric of competitiveness and looking years ahead to make large and strategic investments in their own rapidly expanding research enterprise, for the sole purpose of securing global economic and geopolitical leadership. If we do not make commensurate investments in talent and ideas here, we lose.

Sincerely,

Marcia McNutt

Marcia McNutt
President, National Academy of Sciences

Responses by Dr. Patrick Gallagher

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Maintaining U.S. Leadership in Science and Technology"

Questions for the Record to:
Dr. Patrick Gallagher
Chancellor
University of Pittsburgh
Submitted by Congressman Bill Posey

- **Question 1** – NASA has a storied history of heroic astronauts and amazing feats that all rest on science and engineering. Along the way people realized that our space program often gives rise to science and technology and products that finds their way into our everyday lives. We call these products "spinoffs" and some of them…like the chips in our phone cameras…have become everyday parts of our lives. NASA publishes an annual magazine called "Spinoff" that has documented over 2000 contributions of NASA research to other fields. Are other R&D organizations celebrating "spinoffs?" Do panel members believe that other federal R&D activities could help the cause of science by doing what NASA has done with "Spinoff" and its technology transfer initiatives?

- **Question 2** – We rely on science to produce knowledge that fuels innovation in our economy. Knowledge is an interesting economic good. Once knowledge has been produced, the cost of the next person using it is about zero. It would seem to be inefficient not to let everyone benefit from knowledge once it's been produced. Yet we understand that without incentives to produce knowledge, much of it simply wouldn't be produced. To provide these incentives we have our intellectual property rights system and patents. We're here today talking about the role of government in sustaining scientific leadership and one of our tools to do that is intellectual property. Does the panel believe that we are striking the right balance with our intellectual property system and providing enough incentives to sustain our leadership in science?

- **Question 3** – What's the most important thing Congress can do to sustain our leadership in science?

Submitted by Congressman Bill Posey

- **Question 1** - NASA has a storied history of heroic astronauts and amazing feats that all rest on science and engineering. Along the way people realized that our space program often gives rise to science and technology and products that finds their way into our everyday lives. We call these products "spinoffs" and some of them... like the chips in our phone cameras...have become everyday parts of our lives. NASA publishes an annual magazine called "Spinoff' that has documented over 2000 contributions of NASA research to other fields. Are other R&D organizations celebrating "spinoffs?" Do panel members believe that other federal R&D activities could help the cause of science by doing what NASA has done with "Spinoff' and its technology transfer initiatives?

ANSWER:
Most academic research universities do as much as they can to celebrate their technology commercialization successes. Typically, each "technology transfer" office at a university has a marketing function that not only is advertising the innovations it has which are available for licensing but are also proclaiming their wins. Showcasing the success an organization has had in translation serves as a way to demonstrate to the marketplace of potential partners that the innovations being developed on campus are more than just research projects but rather they are innovations with commercial potential addressing market needs.

Each research university has developed its own publically available database of technologies available for licensing. As a result, there is no single clearinghouse advertising the innovations created across the federal funding landscape that are available for partnering. Rather, interested parties must traverse through sites found at each university or identify for-profit companies that have created min-databases of interesting technologies from a select group of academic centers. Some of these sites have no charge associated with being part of the listings but for others there are significant fees associated with this form of advertisement. Having a single display of the innovations resulting from federally funded R&D activities would be a potentially interesting proposition assuming that such a compendium was easy to navigate, updated regularly, contained appropriate contact points, was responsive to user feedback and was professionally developed.

- **Question 2** - We rely on science to produce knowledge that fuels innovation in our economy. Knowledge is an interesting economic good. Once knowledge has been produced, the cost of the next person using it is about zero. It would seem to be inefficient not to let everyone benefit from knowledge once it's been produced. Yet we understand that without incentives to produce knowledge, much of it simply wouldn't be produced. To provide these incentives we have our intellectual property rights system and patents. We're here today talking about the role of government in sustaining scientific leadership and one of our tools to do that is intellectual propel ly. Does the panel believe that we are striking the right balance with our intellectual property system and providing enough incentives to sustain our leadership in science?

ANSWER:
Obtaining intellectual property protection on an innovation is one of the most important items an organization must focus on to ensure the discovery it has made is afforded appropriate coverage for

it to serve as the basis of a product or service that can enter the market and provide societal benefit. The exclusive rights conveyed by such protection facilitates the creation of a strong market position preventing others from using the innovation and provides the opportunity to enter into unique arrangements with others that desire to obtain access to the discovery.

As the United States has one of the most heralded legal systems in the world, obtaining intellectual property protection on an invention is something that is extremely valuable for purposes of entering the US market. Such protections provide a strong incentive for an organization to engage in research and development activities knowing that the fruit of this investment may result in an idea that cannot be replicated by others. Given that the inventive capacity of the US is continually rising, these protections will continue to allow our country to remain at the forefront of many major scientific and technological breakthroughs in the years to come.

With the increasing rate of speed of these inventions being developed, it is important that such intellectual property protections remain steadfast. One of the major challenges however is that other countries with large and growing markets for US goods do not have the same resolute attitude towards intellectual property enforcement. As a result, the economic potential of products resulting from the significant research and development investments made in the US is diluted when they reach the shores of other countries. This lack of adequate intellectual property protection therefore negatively impacts the ability of US companies to sustain longer-term investments in innovation development.

- **Question 3** - What's the most important thing Congress can do to sustain our leadership in science?

ANSWER:
The single most important thing that Congress can do to sustain US leadership in science is to grow the country's funding of early stage research. Government funding is the bedrock from which most critical research breakthroughs are discovered and the STEM workforce both developed and trained. It is this financial support that triggers the knowledge cascade ultimately leading to innovations that provide broad societal impact as well as a collection of highly curated researchers than can take advantage of these advances. While industry dollars are certainly required to grow our scientific position, these investments are typically focused on enhancements to existing product offerings rather than seeking to comprehend fundamental scientific principles. Without increased levels of early stage government research capital, the US will begin to cede the front-running role it has held for so long across many important areas of technical discovery. Our nation's research enterprise must continue to maintain its global leadership position, which begins with broad research funding.

HOUSE COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Maintaining U.S. Leadership in Science and Technology

Questions for the Record to:
Dr. Patrick Gallagher
Chancellor
University of Pittsburgh
Submitted by Congresswoman Mikie Sherrill

1. New Jersey is home to tremendous research institutions, such as Drew University, Bloomfield College, which gets NASA education grants, Rutgers, and Stevens Institute of Technology which is leading the nation in quantum mechanics. Just down the road are Fortune 100 firms such as Novartis, Verizon, GE, and cutting-edge chemistry research companies Evonik.

   What more can Congress do to advance partnerships between research institutions and innovative companies that can bring discoveries to market?

2. I also have several questions for the record to address strengthening quantum research, both for defense applications and US economic competitiveness.
   a. What are the most urgent/promising lines of research in quantum both for defense-related applications as well those applications that will have direct impact on U.S. economic competitiveness?
   b. What are the existing U.S. strengths and capabilities in quantum research that should be exploited?
   c. In what areas is the U.S. lagging behind other countries in quantum research—both in pure and applied research?

Submitted by Congresswoman Mikie Sherrill

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   What more can Congress do to advance partnerships between research institutions and innovative companies that can bring discoveries to market?

   ANSWER:
   Since its inception, the Bayh-Dole act has facilitated a great number of university created innovations transitioning from the academic lab in which they were invented to a for-profit entity with the capability of turning this idea into a product or service benefitting society. At the University of Pittsburgh alone in fiscal year 2018 Pitt received 363 invention disclosures, entered into 162 licenses/options, received 98 issued patents and spun out 23 new companies based on technologies developed in our laboratories through use of federal funds.

   However, despite these ever growing translational numbers, there are elements of Bayh-Dole that inhibit an even greater number of partnerships between research institutions and outside organizations looking to commercialize these discoveries. The items listed below would help enhance the ability of research institutions and companies to collaborate on bringing university ideas to market;

- **Better defining the government use license that applies to all federally funded inventions.** Currently the intention of this "nonexclusive, nontransferable, irrevocable, paid- up license to practice the invention or have the invention practiced throughout the world by or on behalf of the Government," is not well articulated causing concern to companies seeking to license technologies from universities created with federal funds. Organizations are uncertain as to who can invoke this right and the scope it affords the government.

- **Plainly expressing the conditions required for the government to exercise its "march-in rights"**. While the federal government does reserve its right to step into the shoes of the licensor if the licensor does not execute an assignment or license to a "responsible applicant", the intent and mechanisms that would lead to such use of rights are not clearly articulated. Thus, potential licensees of federally funded innovations are concerned about the federal reach through that exists if there is some arbitrary determination the licensee is not fulfilling its commercialization obligations.

- **Examine US manufacturing requirements for exclusive licenses.** Bayh-Dole requires products made with innovations created with federal funds to be "substantially manufactured in the United States". As we are increasingly living in a global world and companies that universities partner with have broad manufacturing value chains, it is often difficult to ensure a product incorporating a federally funded invention is manufactured in the US. Not only may this company be located outside the United States, but the majority of the product the licensee is making may consist of technology from other sources and not centrally based on the academic discovery. Further, the definition of "substantially" is a point that requires additional clarity. Improving the efficiency of the existing waiver process for obtaining approval to manufacture elsewhere and ensuring that conditions are not being developed to constrict a broad set of partnering activity are important for bringing discoveries to market.

- **Explore broadening of SBIR/STTR funding to allow award use for IP costs.** Intellectual property is often the core value element of a company, especially an early stage one. It is therefore imperative that a company ensures its IP is properly protected. However, one of the single greatest costs for any early stage company are those related to protecting its intellectual property. As such, these companies are put in the position of needing to tradeoff protecting an expensive, intangible asset or fund the tangible machinery that will create value from the idea covered by the intangible asset. Currently, SBIR/STTR grant funding can not be used for intellectual property protection but allowing some amount of this funding to do so would help ensure that earlier stage companies universities engage in licensing transactions with are capable of simultaneously protecting licensed IP and while bringing this invention to marketplace.

2. I also have several questions for the record to address strengthening quantum research, both for defense applications and US economic competitiveness.
    a. What are the most urgent/promising lines of research in quantum both for defense-related applications as well those applications that will have direct impact on U.S. economic competitiveness?
    b. What are the existing U.S. strengths and capabilities in quantum research that should be exploited?
    c. In what areas is the U.S. lagging behind other countries in quantum research- both in pure and applied research?

ANSWER:

a. The portfolio of quantum research spans a wide range in terms of expected payoff. The major areas (in order of increasingly near impact) are: quantum computation, quantum simulation, quantum communication, and quantum sensing. Quantum sensing is an area that has direct relevance for defense applications as well as US competitiveness. Precision measurements of fundamental quantities (like frequency) have relevance to global positioning systems, for example, which has clear commercial as well as defense-related applications. Advances in quantum sensing will also feed forward to all of the other longer-range technology goals in the quantum space (i.e., quantum communication/simulation/computation). For example, quantum sensing with photonics is central to the challenge of quantum communication, and is important for reading out results of a quantum simulator or quantum computer. Quantum measurement of quantum bits (qubits) is central to the challenge of developing a quantum computer. A cross-cutting research effort that is very important for this field is the development of quantum materials. Quantum technologies cannot be abstracted from the physical systems that embody them. We are constantly searching for (and trying to design) new families of quantum materials that can enable the quantum technologies—all of those described above.

b. The US is currently in the lead in quantum research in most of the areas described above. This lead came from decades of groundbreaking fundamental research in US Universities, national laboratories, and industrial groups. However, the lead is narrowing due to intense global interest and investment from EU, China, and elsewhere. Quantum materials research is also being led in the US, especially topological phases and 2D materials. These materials are indeed ripe for exploitation in many (if not all) of the major quantum sectors.

c. The US is definitely threatened by intense research efforts in China to develop a quantum internet. They have provided enormous resources to create quantum satellite technology, and the breakthroughs that were published (openly) demonstrate a clear advantage. There is a long way to go before these technologies really become useful, but the US is lagging behind (as far as we can tell based on open literature). It is unfortunate that a field that was created 100% in the US (quantum key distribution) based on fundamental research is benefitting other countries more than the US itself. There will be more examples of US leadership in quantum research being overtaken by China and other countries, unless a strategy is put in place for maintaining US leadership.

Responses by Dr. Mehmood Khan

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COMMITTEE ON SCIENCE, SPACE
AND TECHNOLOGY

Compete.
Council on Competitiveness

April 19, 2019

The Honorable Eddie Bernice Johnson
Chairwoman, Committee on Science, Space, and Technology
House of Representatives
Congress of the United States
2321 Rayburn House Office Building
Washington, DC 20515-6301

Attn: Mr. Ben Berger

Dear Chairwoman Johnson:

Thank you for your letter dated March 22, 2019 and for your kind remarks regarding my participation in the March 6, 2019 hearing entitled "Maintaining U.S. Leadership in Science and Technology."

I was honored to take part in that hearing in my role as Chairman of the Council on Competitiveness, and as Vice Chairman and Chief Scientific Officer of PepsiCo.

Since the hearing, I have taken on a new position as CEO of Life Biosciences, though I maintain the chairmanship of the Council on Competitiveness. And the Council's members - across industry, academia, labor and our national laboratory complex - and I look forward to working with you and the Committee to enact meaningful change that will improve the nation's scientific, technological and innovation edge.

I also appreciate the opportunity to respond to the set of questions you have shared from your colleagues, Congresswoman Mikie Sherrill and Congressman Bill Posey. Below, I offer responses that I trust will be of use to you and your fellow Members.

Sincerely,

Mehmood Khan MD, FRCP, FACE
CEO
Life Biosciences

-and-

Chairman
Council on Competitiveness

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Questions for the Record (reproduced here), submitted by Congresswoman Mikie Sherrill

1. In February, I met the girls at Exit 5A Robotics Team in Livingston. They are on one of the leading robotics teams in New Jersey, and compete in the World Robot Olympiad. They are pushing the boundaries of hands-on experience for students in STEM.

   Their talent and enthusiasm carries through to college, where women earn half of all STEM degrees. But in the workforce, women comprise only 15% of America's engineers. What work is the Council on Competitiveness doing to bring women with STEM degrees into science careers?

   Dr. Khan's response:

   For over three decades, the Council on Competitiveness (www.compete.org) has worked to elevate to national attention the case that diversity and inclusivity in our STEM workforce is one of the nation's competitive advantages.

   We have undertaken a range of studies and initiatives to drive policy discussion, as well as concrete action, to encourage greater participation of women in America's great science and engineering-based fields, domains and industries.

   I encourage you to check out our website for the full range and history of our efforts in this space - but I will highlight here two successful efforts.

   The first is our "Exploring Innovation Frontiers Initiative" with the National Science Foundation. Launched in 2015, EIFI was a national, public-private effort to accelerate over-the-horizon, transformative innovation models that will drive U.S. competitiveness in the coming decades.

   During the course of EIFI, the Council and its members convened a series of distinctive, expert dialogues to uncover best practices and new recommendations to strengthen the spectrum of innovation - from discovery to deployment in the marketplace. Drawing on lessons learned from each of these dialogues - in Atlanta, Houston, Riverside and St. Louis - the Council issued a set of reports, along with a final, initiative-wide report, "Transform."

   I would call your attention specifically to our dialogue in Riverside, co-hosted with the Chancellor of the University of California Riverside, that focused squarely on identifying key best practices and recommendations to enhance the experiences and roles of women (and other underrepresented populations) in STEM.

   The report from this dialogue, "Diversify: Talent, Diversity, Accessibility, and Inclusion in the U.S. Innovation System", for example, highlights a powerful keynote from UC Riverside's Dr. Susan Wessler - who discusses the "upstairs and downstairs" of American research universities, and the creation of innovative models to get more women and underrepresented populations engaged in science more quickly, more deeply and more profoundly than in most universities.

   These sets of activities underway at UC Riverside are worth further study and even scaling at the national level - as they are transforming the mindset in STEM education away from "weeding out" to "inclusivity."

Below, I attach links to relevant studies and recommendations from this one Council on Competitiveness project.

https://www.compete.org/exploring-innovation-frontiers-initiative/main

https://www.compete.org/eifi-atlanta

https://www.compete.org/eifi-houston

https://www.compete.org/eifi-riverside

https://www.compete.org/storage/documents/eifi%20riverside%20post%20report%20final.pdf

https://www.compete.org/eifi-stlouis-regional-dialogue-series-page

https://www.compete.org/storage/reports/transform.pdf

The second Council on Competitiveness initiative to help drive greater engagement of women and other underrepresented populations into STEM education and careers is our "National Engineering Forum" - also known as "NEF."

NEF started as a partnership between the Council on Competitiveness and the Chief Technology Officer of Lockheed Martin to elevate to national attention the role that engineers and the engineering enterprise play in America's long-term productivity and prosperity.

NEF took Council members on a multi-year journey to nearly 20 cities across America to document best practices in engineering - including how to attract, engage, mentor and keep women in engineering or engineering-related fields (in industry, academia, our national labs, etc.)

I embed here a series of links documenting this incredible trek across the United States, drawing your attention in particular to the third link - our initial report and findings from the NEF initiative.

https://www.compete.org/programs/previous-work/28-national-engineerng-forum

http://nationalengineeringforum.com

http://nationalengineeringforum.com/wordpress2/wp-content/uploads/NEF-Report-MID.pdf

https://twitter.com/NatlEngForum

2. I also have several questions for the record to address strengthening quantum research, both for defense applications and US economic competitiveness.

    a. What are the most urgent/promising lines of research in quantum both for defense-related applications as well those applications that will have direct impact on U.S. economic competitiveness?
    b. What are the existing U.S. strengths and capabilities in quantum research that should be exploited?
    c. In what areas is the U.S. lagging behind other countries in quantum research - both in pure and applied research?

Dr. Khan's response:

I will address your questions generally, summarizing key findings from recent research undertaken jointly by the Council on Competitiveness, Deloitte, Singularity University (and featuring commentary and perspectives from Dr. Davide Venturelli, Quantum Computing Team Lead and Science Operations Manager, USRA Quantum AI Laboratory at NASA Ames).

After nearly 20 years of theorizing and experimenting, major computer hardware companies, venture capital firms, and governments (led by the European Union, Australia and Canada) have finally begun investing heavily (more than a billion dollars combined) to kick-start the industrial age of quantum computing.

Quantum computing (QC) is a manifestation of the attention of the tech world to paradigm-shattering new approaches to computation. It needs to be contextualized within the many different hardware approaches (e.g., Annealers, Optical Coherent Machines, Neuromorphic, DNA-Computing, Spintronics) that are being proposed to circumvent the computational bottlenecks produced by scaling the quality of solutions for problems arising in machine learning, big data, and optimization.

A combination of two factors is driving industrial interest in quantum computing:

- Realization that these computer science problems could benefit from special-purpose, hardware-optimized devices designed specifically to accelerate the solution and reduce the energy consumption of particular classes of problems.
- Fear of missing out on being an early mover in what could be a key competitive advantage in the next decade.

Another factor increases QC's future appeal - it has the potential to offer some known, algorithmic-level advantages which, at a large scale, would be mathematically unbeatable by any non-quantum information processing technology. (The caveat is that these known advantages would not be practical for more than a decade at quantum computers' current and project growth of power. Even when the known algorithms become runnable, their impact on industrial optimization and artificial intelligence is not likely to be a game-changer.)

Notwithstanding QC's known advantages, forward-looking enterprises and investors are mostly fascinated by the unknown. It may be possible to invent quantum algorithms that could be practically deployable within a decade and could deliver exponential speed-up. But we don't yet know enough about quantum information processing to determine this, and we won't likely learn much more about this elusive field of applied science unless and until we have a quantum computer to play with - a classic chicken-and-egg problem.

There is no clear "big win" in sight, but QC as a research field has grown exponentially in the last five years. Today, the community at large encompasses nearly 10,000 researchers - many in the United States - not including the numerics practitioners in finance, optimization, and AI, who are approaching the field from the perspective of end users.

Innovation departments in charge of automation, operations research, planning and scheduling of robotic operations, value-chain optimization, and machine learning should:

- Evaluate which of the current computation approaches could be ported to benefit from quantum cloud computing in five to seven years.
- Design new, high-end computation systems in a modular way so they could be effectively hybridized with quantum and unconventional dedicated processors.
- Identify which among the current numerical challenges in their business is presenting a significant bottleneck in terms of intrinsic exponential difficulty that could be potentially addressed by disruptive, unconventional methods.

To facilitate this computation evolution, firms like IBM and Google (along with smaller firms like Rigetti Computing, IonQ, et al) are creating an experimentation ecosystem by providing free cloud access to their processor prototypes to qualified researchers. Another groundbreaker has been D-Wave Systems, the first QC company with a commercially viable product - a quantum annealer (i.e., a computer) that can be used as a "black box" to solve discrete optimization problems.

In addition, several government institutions and innovation programs have created collaborative opportunities to test the machine for free; for example, the USRA Research Opportunity Program, which makes available the computer installed at NASA Ames Research Center.

But the bottom line is that there is still a long way to go before making quantum computing "plug-and-play" and that eventual success is likely to come from a hybridized, quantum-classical system dedicated to solving specific problems that are collaboratively identified with the end-user community.

However, the U.S. National Quantum Initiative Act - signed into law by President Trump on December 21, 2018 - is a significant development, demonstrating to the world through its 10-year, $1.25 billion+ commitment that the nation is taking seriously the opportunity (as well as confronting the global competitiveness challenge). The Council on Competitiveness supports this Act - and I would also commend to the attention of Members of Congress the recent work by the National Academies of Science, Engineering and Medicine's latest report, "Quantum Computing: Progress and Prospects."

Note: Potential Future Applications of Quantum Computing

- Inspecting infrastructure; enabling intelligent supply chains; predicting thepropoerties of futuristic/exotic materials; modeling and simulating real manufacturing processes to fix errors.
- Uncovering new, high-density designs that could considerably increase the capacity of batteries for electric vehicles.
- Analyzing inventory; optimizing logistics and supply chain; marketingoffers to varied consumers.

Questions for the Record (reproduced here), submitted by Congressman Bill Posey

1. NASA has a storied history of heroic astronauts and amazing feats that all rest on science and engineering. Along the way people realized that our space program often gives rise to science and technology and products that finds their way into our everyday lives. We call these products "spinoffs" and some of them...like the chips in our phone cameras...have become everyday parts of our lives. NASA publishes an annual magazine called "Spinoff" that has documented over 2000 contributions of NASA research to other fields. Are other R&D organizations celebrating "spinoffs?" Do panel members believe that other federal R&D activities could help the cause of science by doing what NASA has done with "Spinoff" and its technology transfer initiatives?

Dr. Khan's response:

NASA's activities in this space - both in spinning out technologies and in documenting that success - are commendable.

Organizations across government, industry and academia are certainly "celebrating" spinoffs. And they are doing so because many are increasingly attuned to the power of transferring technologies from labs to the marketplace to create new value in society - this is the definition of innovation.

But there is no single model on how this ought to be accomplished. A magazine that works for one type of organization, may not be the right channel for another.

I would commend the Member to examine the successes, for example, at the U.S Department of Energy and its national laboratory enterprise - one of America's true crown jewels and competitive advantages.

But these labs are doing more than just spinning off technology - they have evolved well beyond this activity which is nearly half a century old. These labs are creatively "spinning in" entrepreneurs to take advantage of their globally distinctive user facilities and tools (high performance computers; light sources; etc.) and personnel in our national labs to create new businesses. Access to these often-one-of-a-kind facilities and talent is a massive de-risking for entrepreneurs and innovators.

The suggestion of the Council on Competitiveness would be, yes, continue to celebrate the success of spin-offs - but also recognize that the game of value creation in a world of hyper global competition has changed, and that new models of innovation and value creation are needed (and that these need as much, if not more, visibility and celebration). I would commend the Member to explore programs like:

Cyclotron Road at Berkeley Lab; Innovation Crossroads at Oak Ridge National Laboratory; Chain Reaction Innovations at Argonne National Laboratory; etc.

2. We rely on science to produce knowledge that fuels innovation in our economy. Knowledge is an interesting economic good. Once knowledge has been produced, the cost of the next person using it is about zero. It would seem to be inefficient not to let everyone benefit from knowledge once it's been produced. Yet we understand that without incentives to produce knowledge much of it simply wouldn't be produced. To provide these incentives we have our intellectual property rights systems and patents. We're here today talking about the role of government in sustaining scientific leadership and one of our tools to do that is intellectual property. Does the panel believe that we are striking the right balance with our intellectual property system and providing enough incentives to sustain our leadership in science?

   Dr. Khan's response:

   The Council on Competitiveness would argue that, in general, the United States is doing a good job in balancing our IP system and providing incentives to sustain our leadership at the cutting-edge of scientific endeavor.

   However, the Council would also argue that the United States needs to do a better job and be more vigilant in addressing the way key global competitors view, respect and enforce intellectual property protection.

3. What's the most important thing Congress can do to sustain our leadership in science?

   Dr. Khan's response:

   From the perspective of the Council on Competitiveness - representing leaders from industry, academia, labor and our national labs - the single most important thing Congress can do to maintain our leadership in science is to commit to sustained, growing funding for science, technology, engineering and mathematics. Cuts to the most basic seed corn of our capacity to innovate, create jobs and wealth and inclusive prosperity are the last thing this nation needs.

   The Council's research over the past 30 years - as well as that of many other organizations - documents this. In fact, our global competitors also agree - as they are doubling down on their own investments in STEM to leapfrog the United States.

   And a recent survey, conducted by Hart Research on behalf of the Council on Competitiveness and 12 other leading industry and scientific societies, documents that an overwhelming majority of American voters support science: 86 percent of American voters say we need more funding in science and technology research - for economic competitiveness and national security.

Appendix II

ADDITIONAL MATERIAL FOR THE RECORD

DOCUMENT SUBMITTED BY REPRESENTATIVE MICHAEL CLOUD

THE

IP COMMISSION

THE COMMISSION ON THE THEFT OF AMERICAN INTELLECTUAL PROPERTY

The Commission on the Theft of American Intellectual Property is an independent and bipartisan initiative of leading Americans from the private sector, public service in national security and foreign affairs, academia, and politics.

IP COMMISSION 2019 REVIEW

Progress and Updated Recommendations

February 2019

Introduction

At the G-20 Summit in Buenos Aires in December 2018, President Trump and President Xi agreed to work toward a pathway for resolving trade disputes and announced a 90-day truce on raising tariffs. The two leaders stated they would "immediately begin negotiations on structural changes with respect to forced technology transfer, intellectual property (IP) protection, non-tariff barriers, cyber intrusions and cyber theft, services, and agriculture."

The IP Commission applauds the administration for seizing the unique opportunity afforded by increased attention on U.S.-China trade relations to address China's structural challenges that promote the theft of IP. This is the work of a generation, and the Commission urges our leaders to see it through.

While there have been many policy developments in the last 18 months related to strengthening the United States' ability to protect IP, there are still a number of ways we could improve those efforts. Below the IP Commission (1) highlights recent developments, (2) reviews new research that demonstrates the continued salience of IP protection to U.S. competitiveness, and (3) offers updated policy recommendations on page 4.

Recent Developments

IP raised to top-tier priority. The Trump Administration has elevated the elimination of China's theft of American IP, whether through cyber-theft, forced technology transfers, stolen trade secrets, counterfeiting of products, or other means, to one of the leading foreign policy priorities and a top goal of the U.S.-China economic negotiations.

Expanded Committee on Foreign Investment in the US (CFIUS) and export controls. The National Defense Authorization Act for Fiscal Year 2019 included the Foreign Investment Risk and Review Modernization Act (FIRRMA) to prevent acquisition of critical U.S. technologies through foreign investment and the Export Controls Act of 2018, which seeks to close loopholes in the export controls process by increasing restrictions on the transfer of emerging and foundational technologies to foreign persons. These new laws will significantly increase protection of IP, but more needs to be done.

Bill introduced to better combat threats to U.S. technology. Senators Rubio and Warner introduced a bipartisan bill in January of 2019 to establish an Office of Critical Technologies and Security to streamline efforts and ensure a whole-of-government approach to protecting U.S. technology. The IP Commission has argued that policy leadership for the protection of IP needs to be a responsibility of the National Security Advisor; this is a step in the right direction.

Increased oversight of military supply chains. The Pentagon has found a "surprising level of foreign dependence on competitor nations." While recent studies of the defense supply chain evaluate more than IP risks, they do include IP as a key factor in their assessments.

New Research

Over the last 18 months there has been a surge in research examining Chinese theft of U.S. IP that supports the IP Commission's findings:

The White House Office of Trade and Manufacturing Policy report on "How China's Economic Aggression Threatens the Technologies and Intellectual Property of the United States and the World" noted that Chinese economic espionage continues to increase and that China is the most active and persistent perpetrator of economic espionage. The report investigates the two primary forms of Chinese economic aggression: acquiring key technologies and IP from other countries, and capturing the emerging high-technology industries that will drive future economic growth and advancements in the defense industry. The report concludes that China engages in systematic economic espionage through a variety of means including cyber-espionage, evasion of export control laws, counterfeiting and piracy, reverse engineering, forced tech transfers, investment and licensing restrictions, data localization requirements, discriminatory IP protections, collection of science and technology information by Chinese nationals at universities, labs, and companies, and investments in private companies and university R&D programs.

The United States Trade Representative (USTR)'s "Findings of the Investigation into China's Acts, Policies, and Practices Related to Technology Transfer, Intellectual Property, and Innovation under Section 301 of the Trade Act of 1974" examined China's industrial policies that call for the "absorption, digestion, and re-innovation of foreign intellectual property" to meet the Made in China 2025 goal of 40% self-sufficiency by 2020 and 70% by 2025. Many of China's means of acquiring IP are not officially written into law but are done in indirect and informal ways that make it difficult to prosecute. Through means such as investments and cyber intrusion, the Chinese government directs and unfairly facilitates the systematic acquisition of cutting-edge

U.S. technologies in industries deemed important by state industrial plans. The report concludes that China's acts, policies, and practices are unreasonable because they unfairly target critical U.S. technology with the goal of achieving dominance in strategic sectors. These practices harm U.S. innovation and economic competitiveness.

USTR's "2018 Report to Congress on China's WTO Compliance" found that despite repeated commitments to refrain from forcing U.S. companies to transfer technology, China continues to do so through market access restrictions, abuse of administrative processes, licensing regulations, asset purchases, and cyber and physical theft. Overall IP enforcement is hampered by gaps in rights protection, civil and administrative recourse mechanisms that fail to deter widespread IP infringement, and insufficient enforcement commitment. The resources, training, initiative, coordination, and transparency required to make real progress in IP enforcement remains lacking.

The Interagency Taskforce (led by Department of Defense) report on "Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States" found that protection of the U.S. industrial base faces an unprecedented set of challenges, not least from the surprising level of dependence on suppliers in competitor nations. For instance, the report notes, "China is the single or sole supplier for a number of specialty chemicals used in munitions and missiles."

The U.S.-China Economic and Security Review Commission's "2018 Annual Report to Congress" noted the multiple challenges to protecting IP that U.S. firms face when operating in China. The report quotes the IP Commission's findings on the scale and scope of the problem and then delineates the policy tools that the United States has to respond to the theft of American IP. Of note, the Commission highlighted that Section 1637 of the 2015 National Defense Authorization Act gives the president authority—which has never been used—to "prohibit all transaction in property" of any person determined to have conducted "economic or industrial espionage in cyberspace."

The Department of Defense Defense Innovation Unit Experimental's report, "China's Technology Transfer Strategy: How Chinese Investments in Emerging Technology Enable a Strategic Competitor to Access the Crown Jewels of U.S. Innovation" found that from 2015 to 2017, Chinese participation in venture-backed startups was at a record level of 10-16% of all venture deals (currently exceeds $100 billion), up from 6% from 2010 to 2015. China is especially investing in foundational technologies including artificial intelligence, autonomous vehicles, augmented/virtual reality, robotics, gene editing, and blockchain technology. Investments in these technologies represented 40% of their investments in 2016. Many of these are dual-use technologies that will be key to the superiority of the U.S. military. As China seeks to meet its Made in China 2025 goals, it is ramping up its R&D spending to 2.5% of GDP and investing in mega projects in core electronics, chips, software, satellites, the next generation of broadband wireless communications, quantum communications, and classified defense projects. The Chinese Communist Party is highly involved in coordinating public and private investment and other vehicles of technology transfer to accomplish its economic and strategic goals. The report recommends the United States implement defensive policies such as CFIUS and export controls reforms (already in progress), introduce immigration and visa policy reforms for foreign students so they can stay in the United States with the knowledge they have attained at U.S. graduate schools, and increase the level of counterintelligence resources. Recommended proactive policies include increased funding for research, incentives for U.S. students to study STEM fields, pro-growth and productivity-enhancing economic policies, and finally, a whole-of-government approach with a coordinated strategy across multiple agencies and departments.

USTR's 2018 Special 301 Report placed China on the Priority Watch List due to critical IP concerns, including trade secret theft, online piracy and counterfeiting, a high volume of manufacturing and exporting counterfeit goods, technology transfer requirements, mandatory application of adverse terms to foreign IP licensors, localization requirements, and weak enforcement. The report points out that China has continuously failed to implement its promises to strengthen IP protection. However, there is positive momentum in China's judicial reforms that include its specialized IP courts and tribunals, which demonstrate competence, expertise, and transparency to a greater degree than other Chinese courts. Notwithstanding these positive developments, interventions by local government officials, powerful local interests, and the Chinese Communist Party remain obstacles to the independence of the courts and rule of law.

MITRE's "Deliver Uncompromised: A Strategy for Supply Chain Security and Resilience in Response to the Changing Character of War" report made a sophisticated argument for the importance of understanding supply chain security of the defense industrial base—of which the protection of IP is a critical element—as a fundamental component of national security in an era and environment of changing and increasingly asymmetric threat.

What Remains: IP Commission Updated Recommendations

There has been much progress in research and legislative and administrative action, but there are a number of ways the United States could be more effective in addressing IP theft. Some of these approaches include:

Build independent international database for scoring of entities from foreign countries that pose IP risk

Given the vast number of foreign actors and products in the U.S. marketplace and supply chains that present IP risks, no bureaucratic mechanism can cover the breadth of the problem and effectively prevent the theft of IP. For this reason, the IP Commission proposes to develop a market-based "scoring" system to rate foreign entities from countries known to pose IP risks that seek to do business with U.S. companies or government agencies. Such an approach would incentivize all actors to comply with international laws and values of liberal market economies, as the market would reward entities that score highly with more business and investment opportunities.

The score would draw upon globally sourced, existing data and must be objective and not subject to manipulation. A trusted score of this type, similar to a FICO credit score, will empower all law-abiding companies, organizations, government agencies, and individuals to make more educated decisions about the level of risk they are incurring before doing business with a foreign entity.

There is currently no mechanism that helps U.S. businesses understand the level of risk they face when engaging with a foreign company or that helps the U.S. government identify which companies should not be allowed to invest or do business in the United States. While the Bureau of Industry and Security in the Department of Commerce maintains a denied persons and entity list, this is solely for export controls. Export controls are not effective in preventing the loss of IP. For example, even at the height of the Cold War in the context of a much simpler global economy, the Soviet Union successfully evaded U.S. export controls. The updated CFIUS law, while an improvement, focuses on investment and thus misses the variety of other ways that bad actors siphon off IP.

The recommended database should begin with scoring Chinese actors (including companies and their subsidiaries, state-owned enterprises, and individuals) and then could expand to other countries that pose a national security challenge. The information in this database should be developed in coordination with U.S. allies to enable swift and harmonized responses. Adoption of the scoring system must cause the least possible disruption to the normal course of business.

Use the emergency economic powers already granted to the president to deny access to the U.S. market and banking system to foreign entities found to be directly benefitting from the theft of American IP

Under the International Emergency Economic Powers Act of 1977, the president is allowed to sanction individuals and organizations and to "prohibit any transaction in foreign exchange." Section 1637 of the 2015 National Defense Authorization Act expands this authority to cover "all transactions in property" of any person the president determines "knowingly engages in economic or industrial espionage in cyberspace." We need to make sure the president is using all of these tools that are at his disposal.

Deny access to banking system to foreign entities that use or benefit from the theft of American IP

No foreign entity that steals IP should be able to access the U.S. banking system. The secretary of the treasury should have the authority to deny access to the U.S. banking system to malicious actors. This builds on the existing statutory authority of the president as outlined above and was proposed but not adopted during the prior administration. The IP Commission strongly encourages the adoption of this recommendation to ensure that the United States is well placed to address new and emerging threats on an ongoing basis.

Enforce strict supply-chain accountability for the U.S. government

The IP Commission applauds the Pentagon's announcement that it will audit the U.S. military supply chain to identify weaknesses in the nation's military readiness, as well as former Secretary Mattis's announcement of the Protecting Critical Technology Task Force (PCTTF) to spot leaks in the military supply chain. The Commission recommends increased oversight of supply chains be expanded to the entire U.S. government.

Require the Securities and Exchange Commission to judge whether companies' use of stolen IP is a material condition that ought to be publicly reported

This recommendation is derived from strengthened accountability requirements on foreign firms that seek to be listed on U.S. exchanges. It was included in the original IP Commission report and merits further study.

Instruct the Federal Trade Commission to obtain meaningful sanctions against foreign companies using stolen IP

This recommendation seeks to find meaningful ways to punish willful IP-thieving entities. The modalities of how to do this in effective ways also merit deeper research and policy analysis.

Coordinate investment and export controls

The reforms passed on the CFIUS and the export controls processes in the recent National Defense Authorization Act made enormous strides forward by restricting investment in and potential exports of emerging technologies critical for national security. Now it is urgent that both the Department of the Treasury (which manages CFIUS) and the Department of Commerce (which manages export controls) work closely together to close loopholes and share information on foreign actors that pose risks.

Quickly intercept counterfeit goods

More must be done to quickly identify and intercept counterfeit goods coming into our ports. Development and deployment of new technologies to improve the ability to detect counterfeit goods can support law enforcement in this process. The Commission also recommends strengthening the International Trade Commission's 337 process to sequester goods containing stolen IP.

Streamline the process for reporting and responding to IP theft

The process to stop the sale of products made with stolen IP, especially stolen trade secrets, is costly and time-consuming, and by the time law enforcement and the courts take action the innovator's entire business might have been decimated. For example, by the time that the U.S. Department of Commerce in September 2018 took action against the imports of unfairly subsidized quartz countertops made with stolen technology, Chinese imports were supplanting $1.2 billion of sales per year of U.S.-produced quartz countertops for the American market. There needs to be a simpler way for businesses to report cases of IP theft, for law enforcement to take swift action to bar the sale of the illicit product, and for investigations to quickly proceed and come to conclusion. Authorities must act with haste—within hours or days, not weeks or months.

Establish multilateral policy dialogues

The Commission recommends the United States initiate multilateral policy dialogues with like-minded partners to strengthen and coordinate national policies on Chinese foreign investment and enforcement of IP laws, share information on foreign actors engaging in IP theft, and learn from each other's best practices. The Commission recommends starting with Japan, then including the European Union (especially Germany and France), Australia, and perhaps the Republic of Korea, Taiwan, and Singapore.

Utilize multilateral institutions to harmonize national and international legal and regulatory frameworks

While multilateral institutions like the World Trade Organization (WTO) and World Intellectual Property Organization (WIPO) are not always the most efficient and effective at providing protection of IP from an infringer like China, they can provide an important forum for allies committed to the rule of law and fair markets to chart a path forward, and to incentivize others to adopt the requisite norms and practices. The Commission applauds the United States, Japan, and the EU for their conversations on the sidelines of the WTO on forced technology transfers in China, Chinese industrial subsidies, and reforms to the WTO to better deal with IP violations. The Commission encourages these side dialogues to continue, and recommends bringing in other champions of free trade and high standards for IP protection.

ABOUT THE IP COMMISSION

The IP Commission is an independent and bipartisan initiative of American leaders from the private sector, public service in national security and foreign affairs, academia, and politics. The IP Commission published **reports** in 2013 and 2017 documenting and assessing the causes, scale, and other major dimensions of international intellectual property theft as they affect the United States. The reports also proposed appropriate U.S. policy responses that would mitigate ongoing and future damage of intellectual property rights by China and other infringers.

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- Craig Barrett, former chairman and CEO of Intel Corporation

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