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LEGISLATIVE HEARING ON THE ENDLESS FRONTIER ACT

HEARING

BEFORE THE

COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION UNITED STATES SENATE

ONE HUNDRED SEVENTEENTH CONGRESS

FIRST SESSION

APRIL 14, 2021

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SENATE COMMITTEE ON COMMERCE, SCIENCE, AND TRANSPORTATION

ONE HUNDRED SEVENTEENTH CONGRESS

FIRST SESSION

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LEGISLATIVE HEARING ON THE ENDLESS FRONTIER ACT

WEDNESDAY, APRIL 14, 2021

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

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

Present: Senators Cantwell [presiding], Klobuchar, Blumenthal, Schatz, Markey, Peters, Baldwin, Tester, Rosen, Luján, Warnock, Wicker, Thune, Cruz, Fischer, Blackburn, Young, Lee, Scott, and Lummis.

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

Chair CANTWELL. Well, good morning, everyone. The Senate Committee of Commerce, Science, and Transportation will come to order. Today we have an exciting hearing, I believe, on the future of America's competitiveness when it comes to research and development. And how we move forward on research and development to tech transfer and the most successful strategies of that.

We are honored to have a very distinguished panel in front of us and joining us virtually. The Honorable Kevin Droegemeier, Regents Professor, University of Oklahoma, and former Director of the Office of Science and Technology Policy, and former Acting Director of NSF for Norman Oklahoma, welcome.

Welcome to Dr. Marie Lynn Miranda, Provost of the University of Notre Dame. Thank you so much for joining us here and for your work on so many fronts, but particularly on leading and making our homes and children safer. We so appreciate that.

Dr. Shaw, Provost and Executive Vice President, Mississippi State University, welcome to you and thank you. We look forward to your comments. We put the provosts in the middle, so OK, you can—you can—you can be global and specific at the same time. So, we appreciate that. The provosts are, like, the most important people on the university campus. Everybody wants to get a message in to the provost. What are you going to focus on? So, we appreciate it.

We are joined virtually by Linden Rhoads, General Manager of the W Fund, Seattle. And, Linden, I so appreciate you joining us today. I am so excited for everyone to hear your testimony and the success that the University of Washington has had on tech transfer by being innovative over the last decade.

We are joined by Dr. Gary Butler, Chief Executive Officer of Camgian in Starkville, Mississippi. And it has been great to have a few moments to hear about your success in the AI field and look forward to more comments.

And welcome to Bill Bonvillian, who is also joining us remotely, from MIT's Office of Open Learning in Cambridge, Massachusetts where also servesas a Senior Director. I am sure he has a lot to say about this legislation that has been previewed a year ago, the Endless Frontiers Act, and I think is still being worked on by our colleagues. But, nonetheless, this is the stimulus for a very big debate about America's competitiveness as it relates to research and development and, as I said, commercialization and the tech transfer process.

So, no doubt, even without that, it would be a good time to dust off this discussion. And clearly, with our history as a committee on the America COMPETES and COMPETES Reauthorization Act, we can see a little bit of retrospective of how well, or how well we did not do, on authorizations and appropriations trying to do similar things. Basically, we will look at building and analyzing the ecosystem in which R&D and tech transfer is conducted in the United States of America.

So, today we are here to talk about America's competitiveness and that business competition. And as I mentioned, we have a talented list of witnesses here. We know that we, importantly, do Federal funded research. And between 1996 and 2015, federally funded research led to over $1 trillion in economic growth, and millions of new jobs. Now, I do not know if we are like a venture capital startup, where 1 in 13 are successful. I do not know. But we know that federally funded research, when it comes to even the original R&D done, that was then commercialized with Mozilla, out of the University of Illinois, was a big enough success with the Internet technology, by just some research on how to connect every computer with, you know, hypertext links. This was unbelievable and unleashing. So, it should not be lost on anyone that sometimes with R&D, you just never know what the big breakthrough is going to be.

Today, Federal investment in research and development is at its lowest point in 45 years, when measured against the GDP. It has been essentially flat over the past two decades, with adjustments for inflation. And this comes as international competition is increasing, and other nations are ready to challenge our position on the world's innovation stage. So, since 2000, global R&D spending has risen more than 200 percent. To me, you have to take that into consideration with where we are. While the United States has certainly contributed to that growth, we only spend about 2.8 percent of GDP on research and development, less that some of the big economies like Germany, Japan, and South Korea.

So, Congress has looked at this issue before. As I mentioned, in the COMPETES Acts of 2017 and 2010, we authorized $80 billion in spending across multiple science agencies. And while COMPETES was successful in launching various initiatives, I believe the Advanced Research Project, ARPA-E program, which for me, being a member of the DOE committee and with Washington being the home to the very prominent Pacific Northwest National Lab-

oratory, I can tell you those monies went to good use and helped us in growing very important, what I would say, solutions to some of our thorniest problems. These include investments in battery technology, how to get intermittent power onto the grid, and leadership in cybersecurity detection on the nuclear weapons front. So, anyway, lots of great work being done there.

Even today, NSF has not fully achieved that funding level that we imagined in America COMPETES. So, Senator Wicker and other members of the Committee, I think one of the fundamental questions for us is what our committee can do to bolster the confidence of our appropriation allies, that these are the right levels of investment and should be adhered to. And so, I hope that we can do that.

So, I know that many of the witnesses today, Mr. Droegemeier, Mr. Bonvillian, will point these important issues out. But I really love the underlying theme in a lot of the testimony in front of us, both about decentralization and how universities play such a key role in, I think, a distributed network of R&D that already exists in the United States. And we should be playing off of that. But also, Mr. Droegemeier and Dr. Miranda, you know about the need for collaboration and the ways to build better aspects of collaboration within these communities and these frameworks. Because, as one noted author said, "Collaboration is the next phase of innovation". You can have all the innovation in an information age and all the information, but if you do not collaborate to get it implemented, then you are not going to innovate. So, I hope that we can keep moving forward.

We know that women and minorities are underrepresented in this area. Dr. Miranda will help address this today, that we need more representation in STEM. In 2019, women made up 48 percent of workers, but only 27 percent of STEM workers. And as noted, COVID–19 made that challenging, because many of these women were also the caregivers in their families. So, how do you be a caregiver and a researcher at the same time? Very complicated. And one research paper said that women's research has fallen 19 percent during this pandemic. So, we know that we have been very affected by this.

So, I want to point out that, you know, Washington—Seattle is probably one of the leading innovation centers in the United States. But I also think that they are becoming students of innovation itself. That is, I think there is an NSF grant the University of Washington is looking at related to some of the successes Rose-Hulman has made in, what I would call, fee-for-service innovation. Rose-Hulman has figured out how to create an engineering and customer service-oriented success. As we are going to hear from the University of Washington today, we will hear how you can take an already very plump research budget and get more out of it by changing the tech transfer system that we have at universities. So, there will be a lot to digest today on this front. And so, I look very much forward to hearing the discussion from our witnesses and from our colleagues today.

I just want to point out, there are a few things that I personally think that we need to be concerned about. We definitely need to make sure we are making investments in not only R&D but our

STEM workforce—building up R&D without the STEM workforce component will be a mistake. We need the workforce. The best research cannot be implemented if we do not have the workforce. And clearly, we are still seeing a shortage in the STEM workforce.

Second, I want to make sure that we continue to think of ourselves as a capitalist country, in how there is nothing better than to put the right money into the right research when capital is on the line. I can tell you this is important in aerospace and in other forms of computer science, as we compete against other nations. The fact that we have capital markets funding the investment creates a level of due diligence that gets us to success. So, I am not saying that any of this is a planned economy strategy. But to the degree that we veer off toward that, I am going to bring us back to something that really focuses on America's capitalism because that has driven more success, and more innovation, I believe.

And so, thank you so much and we will look forward to hearing the witnesses. So, with that, Ranking Member Wicker.

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

Senator WICKER. And amen, and amen. And here I am getting feedback. Thank you, Senator Cantwell, for that very comprehensive opening statement. I welcome our witnesses and guests today, as the Committee considers the concept of an Endless Frontier Act, as well as our Nation's innovation ecosystem.

Investments in science and technology drive economic growth with job creation. America leads the world in science and technology because of our strong innovation ecosystem, which includes roles for government, institutions of higher learning, and industry, as the Chair just pointed out. Maintaining our edge against rising global competition requires continued support for all components of the Nation's science and technology enterprise. China, in particular, is quickly becoming a self-reliant technology power, threatening America's global dominance in advanced industries and technology.

Today's hearing is an opportunity for witnesses to discuss how Congress can advance the innovation ecosystem to ensure the United States remains a leader in science and technology.

Basic research fuels technology development and innovation for every industrial sector. Today's hearing will consider one approach to strengthen technology investments through the, yet to be introduced, Endless Frontier Act.

The major structural changes to the National Science Foundation contemplated in this proposed legislation should not detract from the agency's core mission of advancing basic scientific knowledge. NSF is the worldwide gold standard for basic research agencies, with 236 Nobel Prizes won by NSF funded researchers.

Congress should also ensure that we avoid duplicating R&D missions of other Federal agencies, dozens of which invest in basic and applied research and technology development. Whatever we enact should contain sufficient guardrails to protect the NSF's core mission and coordinate properly with other departments and agencies.

It appears the intent behind this legislation is to help America compete with China. But let me suggest, we will not beat China

by copying its strategy. China is betting that an ambitious, top-down program of applied research and investment, along with subsidies for technology companies, will produce global dominance in key technology areas, yielding both civil and military uses.

Strategic investments in technologies and supply chains are important, but we will not win by simply throwing money at the problem. We could actually end up doing harm if recipients of funding through this concept, lack the capacity and capability to conduct R&D activities that are actually useful.

We also need to guard the fruits of our R&D system by preventing China from stealing American research and technology. So far as I can tell, the proposed bill does not include any provisions to bolster research security and integrity, particularly at our universities. So, we are going to need to address that.

Competing with China means leveraging the talent, expertise, and capabilities found across our entire nation. Presently, about half of all Federal research funding in science and technology ends up at only six states. Unfortunately, this uneven distribution has changed little over the decades. Since we have not actually seen complete bill language, it is not clear to me that the Endless Frontier Act will go far enough to change this paradigm. Future strength of our innovation sector requires that we provide opportunities for all Americans, regardless of where they may live, work, or attend school.

And the distinguished Chair just mentioned disparities and opportunities for young women. I think one of our distinguished witnesses will mention disparities and opportunities for African American college students at the undergraduate and graduate level.

Today, I have the privilege of introducing two Mississippians who have important perspectives on the scientific ecosystem. Dr. David Shaw is Provost and Executive Director at Mississippi State University. For decades he has been at the forefront of the nexus between Federal research, universities, and economic development. I look forward to hearing his insights on how to grow STEM talent in underrepresented states and ensure an equitable distribution of science funding across states and institutions.

Dr. Gary Butler is CEO of Camgian, a leading technology company in Mississippi. Camgian builds and sells products to the government and private sector based on cutting-edge research. Dr. Butler can provide insights on the important role industry plays in bridging the valley of death that exists between research and commercialization.

Madam Chair, it is my understanding that the Endless Frontier Act is to be part of a larger China package envisioned by the leadership. I hope we can continue the Committee's bipartisan tradition of considering the consensus science and technology related legislation. It is worth asking whether President Biden's recent $2.3 trillion infrastructure proposal would spend hundreds of billions of dollars for many of the new or modified programs that would be authorized in an Endless Frontier Act. Authorization and appropriations, of course, should be done in a bipartisan way. I would urge my colleagues to work with me to build consensus on this China proposal in a deliberative manner and make sure we get it right.

Thank you, Madam Chair. This is a very important hearing and I look forward to a great discussion.

Chair CANTWELL. Well, thank you, Senator Wicker, and I certainly plan on working in a bipartisan fashion, on both authorization and appropriation. I know we have two of our colleagues who have been doing that for a year, Senator Young and Senator Schumer. And we appreciate their hard work on that. And so, I agree. I do not think there is anything—well, there is an R&D here, but it is not the Republican and Democrat. It is—Research and Development is really a bipartisan issue.

So, Senator Young, did you want to make further comment in introducing Dr. Miranda? And again, thank you, to you and Senator Schumer for your leadership.

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

Senator YOUNG. Well, thank you, Madam Chair, and I thank the Ranking Member. This is such an important hearing to hold. And I especially want to thank Madam Chair for doing some field research in my home state of Indiana, in preparation for this hearing. Drawing on the insights, for example, of Rose-Hulman, that is doing some ground-breaking work in how we fund research.

But I am honored to be introducing Dr. Marie Lynn Miranda. And honored, also, that she is here to lend her support and endorsement of the Endless Frontier Act. Indiana's expertise in science and technology is extensive and often underappreciated, and we aim to change that. Dr. Miranda's leadership at one of our most distinguished institutions of higher education, is indicative of that. And her joining us today is proof of the importance of this issue in particular, of ensuring that the United States of America, outgrows, out innovates, and out competes the People's Republic of China. Using our unique system, our existing assets, harnessing talent across the country geographically, drawing from different genders, and races, and ethnicities, and using our native creativity.

The doctor is the Charles and Jill Fischer Provost at the University of Notre Dame. Before coming to South Bend, Indiana, Dr. Miranda was a Provost and Professor at Rice University, where she oversaw $230 million in investments. She graduated Phi Beta Kappa, summa cum laude from Duke University, where she later served two decades on the faculty. She also holds a master's degree from Harvard, where she held a National Science Foundation graduate research fellowship. So, she is intimately familiar with the subject matter here today.

Dr. Miranda's resume is remarkable and her accomplishments are countless. But beyond this, the reason her support is so critical to the Endless Frontier Act, and to American innovation more broadly, can be seen in the Children's Environmental Health Initiative, of which she is the Founding Director, commendably. The program uses research and data collection to better understand and address environmental impacts on at-risk children. Applying science and technology, not just to enhance America's competitiveness, or advance America's interest, but to also meet pressing challenges at home and abroad. This is the innovation that the Endless Frontier Act has the potential to inspire.

Now, we are not attempting to prove that what, you know, works in theory might work in practice. We have economic history to draw upon. We have economic history to draw upon. So, over the course of the hearing today, I look forward to drawing, not just on abstract theories or long-standing chibalis or talking points, but also, the history of some of these clusters, that do disproportionately draw the bulk of our venture capital in this country. Discussing why they may draw that disproportionate share of venture capital, in discussing how we could, indeed, harness the untapped potential of regular Americans across this great land.

So, Dr. Miranda, I welcome you. I thank you, again, for participating in the hearing today, and I look forward to your testimony.

Chair CANTWELL. Thank you, Senator Young. And so, let us get at it. Dr. Droegemeier, we are going to start with you. Again, welcome to all the witnesses, and we know that you have submitted longer statements. If you could keep to 5 minutes, we so appreciate it, so we can get questions from members. So, again, welcome, Dr. Droegemeier.

STATEMENT OF DR. KELVIN K. DROEGEMEIER, REGENTS' PROFESSOR OF METEOROLOGY AND WEATHERNEWS CHAIR EMERITUS, ROGER AND SHERRY TEIGEN PRESIDENTIAL PROFESSOR, UNIVERSITY OF OKLAHOMA

Dr. DROEGEMEIER. Good morning, Chair Cantwell, thank you so much. Ranking Member Wicker and members of the Committee, it is a great privilege to be here testifying before you today on the Endless Frontier Act. I am also grateful to the Majority and Minority staff and the great support that they provided in preparing for the hearing.

You know, America has an absolutely amazing science, technology, research, education, and innovation ecosystem consisting of four important sectors—the Federal Government, colleges and universities, for profit private companies, and non-profit organizations. When they join forces toward achieving common goals on specific problems, America sees a whole that is far greater than the sum of the individual parts. In my personal view, this particular point, along with increased funding is the—the key for unlocking transformation in American science technology. And Chair Cantwell mentioned this very point about collaboration.

We saw several examples of this in response to the COVID–19 pandemic and the beneficial results absolutely speak for themselves. And as Ranking Member Wicker mentioned, research security and balancing the appropriate protection of our research assets, with providing the open collaborative environment needed for advancing American science technology is very, very important.

Now, with regard to NSF in particular, successes it has enabled over the more than seven decades it has been in existence, they are well known. But in fact, it has been mostly underfunded for many years, as Chair Cantwell pointed out. So, my first point is at redressing years of failed attempts to increase the NSF budget is a national imperative for American competitiveness.

Second, NSF foundational mission is one of supporting curiosity-based research, and this should not change. However, this research can in fact be augmented with additional use inspired research

which, in fact, NSF already funds in many disciplines, but that is targeted to specific technology domains that enhance America's competitiveness. NSF leadership already is taking several actions consistent with this direction.

A third, increased American competitiveness will only come about, not just by—by increased funding, though funding is very, very, important. But also, by thoughtfully implementing structural changes that are essential, if that funding is to achieve its intended purpose. And, Chair Cantwell, you—you mentioned this point, again. And I elaborated on these very points in my own testimony—my written testimony.

Fourth, if a new technology and innovation directorate is created at NSF, with some DARPA-like characteristics, those characteristics should not be confined just to that new directorate alone. For example, NSF program officers should make big bets on big, but intellectually risky ideas. Some projects should, and in fact must, fail because, in the absence of failure we are not bold in America. And America will not become the leader in science technology, become more competitive by being timid. We have to make big bets on big ideas. And in fact, that directorate should itself be structured to fail, if it works only in isolation from other parts of NSF, or other Federal agencies.

Fifth, the new technology directorate can serve as the organizing mechanism by which to create new multi-sector collaboration frameworks in technology that span the spectrum completely, from fundamental research, through applied development, and across the valley of death, to pre-production prototypes that are tested at scale, all within the same organizational construct. That is, bringing all of these sectors together in ways that we have not done so in the past.

So, in so doing, we do not just create separate funding entities or centers for performing research or moving outcomes to market or establishing test beds and fabrication facilities, we leverage the tremendous capabilities we already have. Everything can and should operate within the same organizing framework, with specific goals, with specific types of problems in mind. This is, in fact, how I think we transform the current process to make it far more efficient, and I elaborate on that in my written testimony.

Also, industry academia non-profits have to absolutely be at the table with the Federal Government from the very beginning, as all of these programs are being contemplated, so that they all can truly be active participants in the entire process, from fundamental research all the way through scaled prototype. Among other things this will provide a mechanism to help ensure long-term sustainability of these new activities that we are going to discuss.

And finally, NSF should be provided the flexibility, working closely with Congress and other stakeholders to, itself, determine the appropriate rate at which programs are ramped up, both in time and, also, in funding, particularly in new technology directorate. You know, NSF has extensive experience doing this, and we really ought to tap that expertise.

To other aspects of the bill, I just want to let you know it is unclear in my mind how some of the investments that are being described will avoid reinforcing existing challenges that already are

there today in our current complex research to market processes. Interactions among the many different types of organizations noted are really also not clear. Nor is it clear to me how the proposed regional technology hubs, at roughly a billion dollars per award, would really be structured and managed, or how those major activities would complement other new investments that are being described in the bill.

And finally, multiple undertakings, as large as those proposed in the bill, they really pose extraordinary challenges and accountability, especially with regard to evaluating the collective activities that are really in place to achieve more than the sum of their individual parts. So, how does that whole really, together, achieve more than the sum of the individual parts?

So, in closing, by bolstering and weaving together all the elements of our research enterprise in powerful new ways, without compromising identity and value of each, or the culture of each, and by appropriately resourcing NSF, we will help ensure not only that America becomes more competitive and more broadly engaging, but in fact, that we will continue to be the global leader in science, technology, research, education, and innovation.

Thank you very much, Chair Cantwell. I look forward to your questions.

[The prepared statement of Dr. Droegemeier follows:]

PREPARED STATEMENT OF DR. KELVIN K. DROEGEMEIER, REGENTS' PROFESSOR OF METEOROLOGY AND WEATHERNEWS CHAIR EMERITUS, ROGER AND SHERRY TEIGEN PRESIDENTIAL PROFESSOR, UNIVERSITY OF OKLAHOMA

I extend my deep appreciation to Chair Cantwell, Ranking Member Wicker, and Members of the Committee for the privilege of testifying on the Endless Frontier Act. My name is Kelvin K. Droegemeier, and I am Regents' Professor of Meteorology at the University of Oklahoma. I also am a former member of the National Science Board (2004–2016), serving the last four years as Vice Chairman. I served as Secretary of Science and Technology in the Cabinet of former Oklahoma Governor Mary Fallin (2017–2019), and most recently served for two years as Director of The White House Office of Science and Technology Policy (OSTP) and Science Advisor to the President (2019–2021). During the latter appointment, I also served for two and a half months as Acting Director of the National Science Foundation (NSF). Before going to The White House in early 2019, I served for nine years as Vice President for Research at the University of Oklahoma (2009–2018), where I have been for nearly 36 years. I am testifying today in my roles as an academic researcher, administrator, teacher, and advisor on matters of science and technology policy.

I also wish to thank the Members of this Committee for their longstanding commitment to fostering national prosperity, economic security, quality education, and international competitiveness through support for fundamental/discovery research and related activities. Not to be overlooked are staff for both the majority and minority, all of whom work exceptionally hard and in a collaborative manner on behalf of our Nation. I am especially grateful for assistance provided to me in this hearing by Gabrielle Slais, Richard-Duane Chambers, and Mary Guenther of Chair Cantwell's office, and by Cherilyn Pascoe, James Mazol, and MaryAsa England of Ranking Member Wicker's office.

The topic of this hearing is especially important in light of increasing challenges faced by the United States, both from within and externally, as well as extraordinary opportunities now before us to build upon—in bold and transformative ways—the exceptional foundation of American leadership in science and technology developed since World War II. That foundation was laid, in large part, in response to Dr. Vannevar Bush's visionary treatise, *Science: The Endless Frontier.*[1] The bold vision put forth by Dr. Bush led to the creation, in 1950, of the National Science Foundation (NSF), which is unique among Federal agencies in two important ways.

[1] *https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm*

First, NSF funds the bulk of non-medical/clinical foundational/discovery/curiosity-based[2] research in the United States.[3] Second, its governing body, the National Science Board (NSB),[4] also serves as an independent source of advice to the President and Congress on matters of science and technology research and education. It therefore is especially appropriate the Endless Frontier Act (EFA) seeks to continue Dr. Bush's bold, transformative thinking by providing substantial increases in funding for NSF, along with creating a new directorate and taking other actions to accelerate the movement of research outcomes to products and services that benefit society.

Such a transformation will come about not only by virtue of additional funding, but also by thoughtfully implementing structural changes that are essential if the additional funding is to achieve its intended purpose. Specifically, success will require creating more effective linkages and partnerships among all sectors of our innovation ecosystem; co-investing and leveraging funding, facilities and talent across academia, industry, Federal agencies, and non-profit organizations; eliminating regulations that unnecessarily tie our hands, impede our progress, and arguably provide little or no practical benefit; and securing our research assets in a manner balanced with an appropriately open system of sharing and collaboration.

Despite the terrible consequences of the global COVID–19 pandemic, it offered us a powerful glimpse of what is possible in America when the aforementioned issues are addressed, albeit temporarily. Although we do not wish to continue operating within a pandemic, we should desire to continue operating with the urgency it brought forth. We should not wish to go back to where we were in our science and technology research and education enterprise, but rather use the lessons learned from the pandemic to go to a much better place. A place of greater efficiency, better coordination, stronger leveraging and partnering, and emphasis on whole-of-Nation goals. The EFA provides one mechanism to do so and will help ensure that science continues to inspire, unite, and guide America.

I offer with this testimony several comments and suggestions regarding the EFA. We should not be comfortable as a Nation to simply compete, but rather our goal should be global collaborative leadership in science and technology research, education and innovation. Underpinned by our national values, which comport with values of the research process itself, America can remain a beacon to the world of freedom, integrity, mutual respect, progress, and principled collaboration.

1. Why Increased Funding for the National Science Foundation (NSF) is a National Imperative

Created more than 70 years ago with a powerfully elegant statutory mandate and organizational structure, NSF has become the envy of the world among government funding agencies. The research it supports has unlocked the secrets of nature—from sub-atomic particles to the vastness of the universe—spurring major technological innovations, creating entirely new research disciplines, and producing generation upon generation of scientists and engineers who help ensure America's global strength in science and technology. Since 1950, over 230 Nobel Laureates have received funding from NSF at some point in their career.[5] NSF's merit review process is the global gold standard, and only a small portion of NSF's yearly budget goes toward supporting organizational overhead.

Despite these and numerous other extraordinary attributes, NSF has been woefully underfunded for many years. The reasons are many, including difficulty by some of conceptually linking fundamental research outcomes with products and services, even though the latter are all around us (*e.g.,* the Internet, search engines, smartphones, medical diagnostic equipment, global positioning system-based maps, on-demand commercial programming); the long time required for some fundamental research outcomes to bear fruit; and the view by some that funding curiosity-based research, without a clear practical outcome, is a waste of money.

The 2007 America COMPETES Act[6] sought to double, over a five-year period, the budgets of NSF, the National Institute of Standards and Technology (NIST), and the U.S. Department of Energy Office of Science (SC). Despite best intentions, this doubling did not occur then, or during the 2010 reauthorization[7]. In 2016, COMPETES became the American Innovation and Competitiveness Act (AICA)[8], which did not include authorization levels. Yet during this same overall period, the budgets of

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[2] I prefer these terms to "basic "research because to some, the word basic connotes "simple."
[3] *https://www.nsf.gov/about/*
[4] *https://www.nsf.gov/nsb/about/index.jsp*
[5] *https://www.nsf.gov/news/news_summ.jsp?cntn_id=100683*
[6] *https://www.congress.gov/110/plaws/publ69/PLAW-110publ69.pdf*
[7] *https://www.congress.gov/111/plaws/publ358/PLAW-111publ358.pdf*
[8] *https://www.congress.gov/114/plaws/publ329/PLAW-114publ329.pdf*

other agencies supporting fundamental research did in fact increase, in some cases substantially,[9] while that of NSF grew more modestly. Today, NSF is forced to decline several billions of dollars in proposals judged to be as meritorious as those it does support, simply due to the lack of funding.

I believe the EFA can help redress years of failed attempts to increase the NSF budget. In light of increasing global competition and threats from nations that do not share our values, an infusion of funds at NSF, along with other actions, truly are national imperatives. NSF already is moving forward on several organizational innovations, and as a major driver of change in the research enterprise, especially academia, NSF is well suited to continue its established leadership role by executing the EFA.

2. The Endless Frontier Act (EFA) in Context

Each sector of America's science and technology research, education and innovation ecosystem—Federal agencies, colleges and universities, for-profit corporations, and non-profit organizations—has its own reasons for existing, its own structures and operating philosophies, and its own measures of success. Although differing from one another—in some aspects dramatically—these sectors are highly interdependent and mutually reinforcing. When brought together in tight collaboration toward common goals, each contributes what the other cannot or will not—both culturally and in other ways—yielding a whole that is far greater than the sum of the parts.

Within this framework, it is well understood that fundamental research is funded primarily by the Federal Government[10] owing to the lack of certainty in producing outcomes having practical value, though value indisputably exists in the creation of knowledge itself. The national appetite for increased Government investment in such research generally has been limited, apart from health-related topics as evidenced by substantial increases to the National Institutes of Health (NIH) budget over the past several years. However, the COVID–19 pandemic has illuminated brightly the numerous other areas of science and technology that have proved essential to our Nation's response.[11] These include but are not limited to molecular and structural biology, *in situ* and remote sensing, advanced manufacturing, artificial intelligence, microelectronics, atmospheric science, and social and behavioral science. Each of these areas and more are core components of NSF, and indeed, NSF's "fingerprints" can be found in virtually every area of capability used to fight the pandemic. And each of these areas yielded basic research outcomes from which innovation led to practical, implementable solutions.

The EFA seeks not only to provide an unprecedented increase in funds to NSF to support use-inspired fundamental research, but also establish a new directorate for technology and innovation,[12] create new research test beds, centers, technology hubs, and fabrication facilities; expand engagement in research of various types of institutions; and substantially increase postdoctoral awards, graduate fellowships and traineeships, and undergraduate scholarships. Understandable fear exists among some in the community about the potential for changing NSF's foundational mission from one of curiosity-based research to one that is driven mainly by practical needs, and these concerns are not without merit.

However, if implemented thoughtfully, the EFA can in fact enhance the capabilities of NSF, strengthening its core purpose while greatly improving the efficiency by which research outcomes are innovated for the benefit of society. Indeed, America needs to supplement the current "handoff and hope" model of research-to-products and services transition with one that more effectively integrates all four sectors of our research enterprise without forsaking the features of any, and without placing itself on the slippery slope of use-inspired technology research becoming the tail

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[9] The NIH budget increased by $12.5 billion between FY 2007 and FY 2020, an increase of 43 percent. The Department of Energy Office of Science budget increased by 3.2 billion between FY 2007 and FY 2020, an increase of 84 percent and thus nearly doubling. The NSF budget increased by $2.4 billion between FY 2007 and FY 2020, an increase of 41 percent.

[10] The private sector, and non-profit organizations, also fund discovery research, with the former funding nearly three-quarters of total research and development in the United States.

[11] Droegemeier, K., 2020. *Harnessing the power of science to fight the coronavirus.* Op-ed, *Washington Times,* August 19. Available at *https://www.washingtonexaminer.com/opinion/op-eds/harnessing-the-power-of-science-to-fight-the-coronavirus*

[12] NSF is structured around seven directorates: Biology (BIO), Computer Information Science and Engineering (CISE), Engineering (ENG), Geosciences (GEO), Education and Human Resources (EHR), Mathematics and Physical Sciences (MPS), and Social, Behavioral and Economic Sciences (SBE). Three other programs support cross-cutting activities: Office of Integrative Activities (OIA), Office of International Science and Engineering (OISE), and Environmental Research and Education (ERE).

that wags the curiosity-based research dog. The EFA can, in my view, serve as one mechanism for achieving those ends.

3. Comments on the Endless Frontier Act Specific to NSF

Point #1. The Potential Risk of Displacing Fundamental Research. As noted previously, virtually all technology innovation owes its existence to fundamental research. That America now has trillion-dollar technology companies, and numerous other high-wealth companies that depend upon technology, is a testament to the virtue of Government investment in fundamental research and our ability as a Nation to transition research outcomes into products and services for the benefit of society. However, *the very size and reach of our technology enterprise suggests care needs to be taken in creating a technology directorate at NSF (see below), lest technology become the focal point for new resources and ironically end up harming the very thing upon which it depends for continued success—fundamental research.*

A good example of this risk is illustrated in the field of meteorology. Both research and operations are critical for protecting life and property, and operational forecasting and warning capabilities depend upon advances in research. However, at the end of the day when money is appropriated, operations always take priority for obvious reasons. This approach led, in part,[13] to the United States being overtaken by Europe in computer weather prediction capabilities, though fortunately, recent investments are reversing that trend. *Fundamental or curiosity-based research therefore must remain the strong philosophical and practical foundation upon which NSF continues to be funded and operate, augmented by, but not replaced with, new mechanisms for engaging use-inspired research in technology domains that enhance America's competitiveness.*

Point #2. Creating a New Directorate. Although NSF indeed was founded to support fundamental or discovery research, a portion of its portfolio appropriately consists of use-inspired research. This is especially true in the Engineering, Computer Information Science and Engineering, Geosciences, and Social/Behavioral/Economic Sciences directorates, and likewise is true in research university departments. Consequently, such work is not foreign to NSF's operating framework or culture, and in fact creating a technology-focused directorate can enhance support for curiosity-based research, as noted below.

The EFA speaks to the importance of bringing DARPA-like capabilities to the new directorate, and I interpret that in at least two ways. The first includes funding more use-inspired research, issuing solicitations that seek to address specific problems, applying DARPA hiring authorities, and engaging industry directly as programs are being structured. The second emphasizes autonomy of program officers to make funding decisions that run counter to prevailing wisdom or reviewer input.

To the first point above, NSF already issues solicitations to address specific challenges and is changing the way it engages industry (see below). To the second point, although NSF program officers do have considerable latitude in making decisions, panel review, community pressure, and budget realities often lead to understandable aversion to intellectual risk-taking. This behavior is not unique to NSF but is prevalent in many if not most funding agencies. *America needs to be willing to make big bets on big ideas that could fail.*

Consequently, if the EFA seeks to bring more of a DARPA-like culture to NSF, it should not confine those attributes to the new directorate, but rather use that directorate to help infuse positive change throughout the Foundation. In so doing, NSF program officers would become more empowered to go against the flow and make big bets on big ideas, with some failure not only an expectation, but rather a desired outcome. *The absence of failure indicates an absence of boldness, and America will not become more competitive by being timid.*

Another important way in which NSF differs from DARPA is the breadth of disciplines and topic areas represented in the NSF portfolio. The new NSF technology directorate can do what other directorates already do, namely, create substantial horizontal connective tissue across directorates and thus a wide array of disciplines. However, *the new technology directorate can play an* ***additional and unique role, by virtue of its special partnerships with industry and other collaborators, in linking curiosity-based research with use-inspired research and subsequent applied development and scale-up (see Point #3).***

The following specific suggestions are offered regarding a new technology directorate to address some of the issues raised above.

a. *A new directorate should not duplicate activities* being undertaken by other Federal agencies (though in some cases competition is warranted), nor should

[13] Another major contributor was insufficient investment in computing resources.

it fund activities likely to be supported by private industry or non-profit organizations. Instead, *the directorate should partner with other components of the research enterprise, including regional, state and municipal entities, to fill gaps and leverage all available resources to achieve a force multiplier effect that accelerates innovation and greatly enhances competitiveness.*

b. Although a new technology directorate should receive sufficient funding to pursue certain activities of its own design, such as issuing solicitations for use-inspired research, developing partnerships with industry, and managing grant and contract programs in a DARPA-like manner, the *structure and level of funding should be designed such that the directorate cannot succeed in achieving its goals in the absence of working in close partnership* with other NSF directorates and other sectors of the research enterprise, including other Federal agencies. *In other words, the directorate should inherently be designed to fail if it works only in isolation.*

c. Changes of the nature and magnitude proposed in the EFA require a time of transition to accommodate institutional cultural adjustment (both within NSF and the external research community), the creation of required or the modification of existing administrative frameworks, and the development of implementation strategies. Yet the length of this adjustment period needs to be balanced with some urgency in light of aforementioned competition and threats. *NSF should be provided the flexibility, working closely with Congress and other stakeholders, to determine the appropriate rate at which programs are ramped up in time and funding, particularly a new technology directorate.* NSF has extensive experience doing so by virtue of the numerous new centers, institutes, and major research facilities it creates on a regular basis.

Point #3. Engaging Private Industry and Non-Profit Organizations. Although, as discussed earlier, the Federal Government funds the majority of non-medical/clinical fundamental research in the U.S., the vast majority of funding for applied research and development, and the transition of research outcomes to products and services, is principally the domain of the private sector (note that some private sector organizations also fund a considerable amount of use-inspired fundamental research on topics related to their business priorities). Yet the intertwined and circuitous pathway from fundamental research, say as performed in academia, to scaled prototype product or service, within industry, is fraught with inefficiency owing to factors such as numerous cultural differences among the sectors involved, the many handoff points present within the overall process, and complex legal issues, particularly those involving intellectual property, that often vary among organizations.

Bringing all four sectors of the ecosystem together for specific activities, with each playing its unique role, creates an extraordinarily powerful framework that will truly transform American competitiveness without forsaking the value or place of fundamental research. Indeed, industry, academia, and non-profits must be at the table with the Federal Government, ***from the very beginning as programs are being contemplated, so they all can truly be active participants in the entire process from fundamental research to scaled prototype.***

This point was underscored during several meetings and a national summit[14] coordinated by OSTP and collaborators during the past two years on multi-sector partnerships. One recurring message, delivered by private industry, was its dismay at typically being brought into discussions of partnering only as programs were being executed, and only at the tactical rather than the strategic level.

The NSF Director already has begun meeting with counterpart institutional leaders in the private for-profit and non-profit sectors to frame partnerships and programs at a strategic level, which will set the stage for, and greatly accelerate progress in, tactical execution. *Such efforts should continue in order that these sectors may co-invest with the Government as active, participatory research and development partners in executing the EFA—including in hubs, fabrication facilities, and centers.*

This co-investment should involve not only funding at the strategic institutional level, but also corporate-sponsored facilities, industry researchers, internships, apprenticeships, enhancements to I–CORPS, fellowships, test beds, and joint activities to engage traditionally underserved and marginalized populations. Indeed, the EFA seeks to create 1000 new post-doctoral awards, at least 2000 graduate fellowships and traineeships, and at least 1000 undergraduate fellowships. Industry partners could co-fund such activities and perhaps triple the number of recipients by creating

[14] *https://uidp.org/new-report-from-ostp-uidp-symposium-broadening-university-and-industry-engagement/*

prestigious NSF industry scholars and fellows, also thereby contributing substantially to increased participation by underserved populations.

A new directorate can serve as the ***organizing framework by which to achieve the aforementioned multi-sector collaboration in technology and thus provide a means for more effectively moving research outcomes across the "valley of death" to become de-risked and tested at scale—the next step being a final prototype for production.*** In this approach, NSF would not be responsible for funding all de-risking and testing at scale, but rather, by virtue of its partnerships with industry, would principally provide the organizing framework by which such activities would take place in a seamless and efficient manner—all the while preserving the cultural elements of NSF so critical to its past and future success.

Such a concept was proposed in a January, 2021 report[15] issued by the previous President's Council of Advisors on Science and Technology (PCAST) and may be useful here. Specifically, PCAST recommended creating a new type of organizational framework that brings together multiple technology areas (*e.g.,* artificial intelligence, advanced manufacturing, and biotechnology) to address compelling practical problems at the intersection of such areas as a complement to recently created centers and institutes.[16] The organizations envisioned by PCAST would conjoin all four sectors of the research enterprise, as equal partners from the outset, and span the entire spectrum from fundamental research to prototype de-risking and scale up—all within the same administrative framework. They also would be structured with streamlined administrative compliance environments, in some cases via Federal waivers of certain requirements that unnecessarily inhibit progress, flexible personnel policies that allow researchers from all four sectors to move across organizational boundaries with ease, and intellectual property frameworks that accelerate the transfer of technology to industry.

By following a strategic, all-sector true partnership model for certain activities, America more broadly will reap greater benefits from the EFA, and the momentum and collective partnership resources thus established will provide a mechanism to help ensure long-term sustainability.

Point #4. More Innovative and Efficient Models for Centers and Hubs. NSF and other agencies have been funding university-based research centers, institutes and facilities for several decades. Although this mode of funding has proven successful, the increasingly prescriptive nature of such efforts, driven in large part by today's burdensome and complicated compliance environment and general aversion to intellectual risk-taking, suggest that modified structures should be pursued. This issue was addressed in the aforementioned PCAST report, which identified a number of significant limitations with current research organizational models and suggested a new multi-sector framework that would stimulate new ideas, simplify collaboration among types of institutions, and accelerate the movement of fundamental research outcomes to products and services at scale, all within the same general framework.

The centers and other entities proposed by the EFA, as well as programs such as EPSCoR (Established Program to Stimulate Competitive Research), could serve as experimental proving grounds for new organizational approaches, including accelerated approvals and waivers of certain compliance requirements and new personnel structures. One need look no further than the COVID–19 pandemic for a compelling example of such an experiment. In *one week,* several organizations joined forces to establish and begin executing a consortium that made huge amounts of both public and private computing time available to researchers, free of charge and with rapid proposal review, to understand the virus and begin developing vaccines and therapeutics. Under normal circumstances, this effort would have taken months to establish.

Point #5. Broadening Engagement. A particularly significant component of the EFA involves programs which seek to engage a larger segment of America's academic research and education enterprise, especially emerging research institutions, emerging institutions of higher education, Historically Black Colleges and Universities (HBCUs), Minority Serving Institutions (MSIs), and Tribal Colleges and Universities (TCUs). I can well attest that extraordinary research accomplishments and talent can be found in all parts of our great Nation, especially in rural and underserved areas, and in institutions which are not research powerhouses but are becoming more engaged in research with a great deal to offer. I also am quite aware that a great number of capable individuals never have an opportunity to develop their talent or achieve their goals and dreams, whether by virtue of their race, ethnicity,

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[15] *https://science.osti.gov/-/media/_/pdf/about/pcast/202012/PCAST_IOTFI-FINAL-Report.pdf?la=en&hash=0196EF02F8D3D49E1ACF221DA8E6B41F0D193F17*

[16] For example, the U.S. Department of Energy Quantum Information Science Research Centers and NSF National Artificial Intelligence Research Institutes.

socioeconomic status, or other circumstances. *Taking firm action to address these and other issues is essential, and in doing so, two important factors need to be considered.*

The first concerns institutional culture. Many emerging research institutions have well established and highly regarded reputations for instruction, with faculty incentive and reward systems likewise structured. Enhancing research in substantial ways most likely will require faculty to reallocate their time, thus reducing their formal teaching activities so they can spend more time writing grant proposals, managing awards and facilities, and mentoring student and post-doctoral researchers. All of these are positive activities and foundational to research in academia. However, because notable increases in such activities can impact both institutional culture as well as existing personnel policies, these and other impacts need to be fully understood by the highest level of institutional leadership. Consequently, *leaders of emerging and other types of research institutions named in the EFA should be engaged as soon as possible to understand how their institutional cultures and policies might need to change, if such change is desired, for them to accommodate greater research funding.*

The second issue concerns the *administrative frameworks needed to support research grants or contracts and associated compliance requirements,* such as financial and other management activities, intellectual property management, legal review, space allocation and tracking, reporting to state and Federal organizations, and research security. Many emerging research institutions have relatively small research offices that are not presently equipped to handle significantly larger numbers of, or more complex research grants and contracts. Nor do they likely have the funding to create or enhance them. Consequently, *some of the funding from the EFA should be used to create new or enhance existing institutional research administration capabilities.* This funding could be provided for a limited period, until such time the institution can absorb the costs by virtue of increased research revenues.

Point #6. Discovering Emerging Intellectual Property. Despite the fact that America invests nearly $600 billion per year in research and development, only limited mechanisms exist, to my knowledge, with which one can identify and then explore emerging research outcomes to determine whether a particular activity holds sufficient promise for possible corporate investment. Some funding agencies have powerful databases with which the public can use keyword searches to obtain plain-language summaries of current and past research projects. Yet, if a small company, for example, is interested in research on a particular topic and wishes to determine which Federally funded projects on that topic are nearing completion—and explore their results to date and contact the investigators—existing databases are not designed to readily provide such information

If the technology goals of the EFA are to be met, *America needs a more effective mechanism for linking progress and outcomes in research to those who wish to innovate with them.* Yet doing so in an open manner creates obvious vulnerabilities at a time when theft of ideas, proposals, and intellectual property by certain foreign governments is a real and significant threat to America's competitiveness. If a new NSF technology directorate is established, it should coordinate with NSF and other organizations to consider ways for addressing these competing needs.

Point #7. Test Beds and Fabrication Facilities. The EFA suggests test beds and fabrication facilities would be located at universities or consortia of academic institutions, which indeed would be valuable for enhancing education and research. However, the private sector already operates substantial facilities that could function as test beds and be used for fabrication through creative partnerships with academia. In particular, use of such facilities could be linked with internships and apprenticeships as a mutual value proposition, which would be particularly important for emerging institutions. Additionally, a partnership strategy would enhance the likelihood of sustainability as some academic institutions, especially emerging institutions, may not be positioned to absorb out-year costs of facility maintenance, staff support and upgrades.

Point #8. Timing and Allocation of Funds. NSF is a highly sophisticated and effective Federal agency that operates with great efficiency and transparency, and works closely and successfully with both the Executive and Legislative branches of Government. It also has extraordinary leadership in its Director and governing board. *Consequently, NSF and the NSB should be provided maximum flexibility and freedom, with obvious continuous oversight from Congress, to execute the EFA as it deems most appropriate for achieving the stated goals.*

4. Comments on the Remainder of the Endless Frontier Act

In addition to changes associated with NSF, which include creating a new directorate, establishing several University Technology Centers, creating test beds and

fabrication facilities, directing funds to STEM education, enhancing existing research programs, and broadening engagement in research and technology commercialization, the EFA seeks to establish several Regional Technology Hubs. Consideration also is being given in Washington, DC to substantially expanding the current Manufacturing USA Institutes (MUI) and Hollings Manufacturing Extension Partnerships (MEP). Collectively, this represents an extraordinarily large and complex endeavor which underscores the well know adage that it is far easier to create than coordinate. Thus, several important issues need to be addressed if the proposed infusion of significant funds, and the associated creation of large and complex activities in America's research and technology enterprise, are to work as needed.

First, as noted previously, America's innovation engine suffers from a number of inefficiencies, including the lack of a seamless national framework by which multiple sectors of the enterprise can seamlessly transition fundamental research outcomes to scaled prototype products and services. It is unclear how investments in the Department of Commerce will avoid reinforcing challenges with existing handoff points and address the "valley of death" problem?

Second, although the EFA speaks to the importance of coordination with the MUI and MEP programs, it does not address the many ways in which a new NSF directorate, or increased NSF activities in technology-driven fundamental research more broadly, could contribute to enhancing both the MUI and MEP programs or lead to new, innovative approaches for executing the MUI and MEP missions. Nor does it address how MUI and MEP might coordinate with and enhance NSF activities, especially corporate engagement, which is foundational to both MUI and MEP. This interaction is especially important in light of ways in which MUI and MEP can enhance engagement with emerging institutions, which is a significant aspect of NSF's focus in the draft bill.

Third, the proposed Department of Commerce Regional Technology Hubs appear designed to create confederations of stakeholders within multiple sectors of a region with the goal of enhancing technology development, creating jobs, and transforming local and regional economies. Although this is an important and valuable idea, such top-down approaches often fail to align stakeholders with common goals because they lack a "grass roots" push. Once again, coordination is one of the many challenges needing to be addressed. If the Hubs are scaled as described in the bill, at roughly $1B per award, additional clarity is needed regarding how the confederations would be structured and managed to "create the conditions" for economic development and education enhancement. Additionally, how would such large funding completement new investments made within NSF as well as programs such as MUI and MEP—all of which are candidate components of a confederation?

Fourth, throughout the EFA, coordination and collaboration among multiple Federal agencies is rightly cited as critical to success of the programs described. Such coordination historically has proved extremely difficult, particularly for the scale and complexity of programs envisioned in the EFA and in light of the multiple stakeholder sectors involved. One possible coordination mechanism would be to create a special, select or joint committee within the National Science and Technology Council (NSTC), co-chaired by OSTP and the Office of Management and Budget (OMB) and involving NSF, the Department of Commerce, and other departments and agencies as deemed appropriate. Based upon my experience with major multi-agency Government programs, front-line OMB involvement is essential for ensuring inter-agency coordination.

Finally, multiple undertakings as large as those proposed in the EFA will create extraordinary challenges in accountability, especially with regard to evaluating how the collective of the activities are achieving more than the sum of their individual parts. To be effective, the various elements need to work together in ways different from and more effective than previously, which creates complex interdependencies. This is a feature and not a limitation, but will require careful thought in how success is defined and measured, and how the various EFA elements contribute to success individually and collectively.

5. Final Thoughts

America today boasts the greatest research, education, and innovation ecosystem in the world. Although we do not lead in every area, the collective of our four-sector enterprise, underpinned by our values, is unmatched. Yet we face unprecedented threats and competition. *By bolstering and weaving together all elements of our research enterprise in powerful new ways, without compromising the identity, culture and value of each, and by appropriately resourcing NSF, we will help ensure not only that America becomes more competitive and broadly engaging, but also that it continues as the global leader in scientific and technological research, education and innovation.*

Chair CANTWELL. Thank you, again, Dr. Droegemeier, for being here. And now, we will turn to do Dr. Miranda.

STATEMENT OF MARIE LYNN MIRANDA, PH.D., CHARLES AND JILL FISCHER PROVOST, PROFESSOR OF APPLIED AND COMPUTATIONAL MATHEMATICS AND STATISTICS, DIRECTOR OF THE CHILDREN'S ENVIRONMENTAL HEALTH INITIATIVE, UNIVERSITY OF NOTRE DAME

Dr. MIRANDA. Madam Chair, Ranking Member Wicker, and Members of the Committee, on behalf of the University of Notre Dame, I am honored to appear before you today. Chair Cantwell, thank you for your commitment to scientific discovery and innovation, including empowering pathways for women and other underrepresented groups within STEM fields.

I also extend greetings to my own Indiana Senator, Todd Young, who is working with Senator Schumer to author the Endless Frontier Act. Thanks to all of you for your good work.

At Notre Dame, our mission is to be a force for good in the world. I myself have spent more than 30 years as a use-driven, or applied, researcher who deploys Bayesian spatial statistics to identify impacts of and solutions to environmental and social threats to children. While I am a use-driven researcher, I rely heavily on basic science or curiosity-driven research. Use-driven researchers and curiosity-driven researchers interact constantly, discussing problems, challenging each other, and sharpening each other's work. As an example, I have long worked on childhood lead exposure, specifically interested in using spatial analysis to identify houses where children are most likely to be exposed to lead, so that we can prevent future exposure.

Federal investments in geographic information systems, and in computational power and speed, made it possible for me to analyze millions of observations on desktop computers. Housing departments use our models to prioritize housing rehabilitation dollars, working with property owners to make homes lead safe. Health departments use the models to drive lead screening programs, resulting in a 600 percent increase in their ability to identify children with elevated blood lead levels at no additional cost. As a result, thousands of children were protected from potential loss of IQ, learning and behavioral disorders, attention deficits, and other negative neurological effects.

My own path to doing this work moved from mathematics to economics to toxicology to statistics. I emphasize path over the usual STEM pipeline metaphor because pipeline implies that there is only one intake point and one outtake point, with some leaks along the way. In fact, members of the STEM workforce travel different paths. Some paths are smooth and direct. Some meander and traverse rough terrain. Some lead to PhDs and some to associate degrees. Some have multiple entry points. Some have only one. We need to support all of these paths to build the STEM enabled workforce required to ensure national security and national competitiveness and to solve our most challenging social problems.

The ability of the U.S. to meet the demand for individuals with the knowledge, skills, curiosity, and creativity necessary to enter STEMs careers is hindered by the lack of women and underrep-

resented minority populations in STEM fields. While there are about 5 million people in the U.S. employed in computing occupations, only 24 percent are women, and 15 percent are underrepresented minorities. If we fail to get the full diversity available to us onto those STEM paths—diversity defined by gender, race, ethnicity, income, geography, our STEM workforce will simply be too small. It will also lack perspectives that encourage creativity and innovation.

In my written remarks, I offer eight recommendations regarding the proposed legislation. Here, I highlight three. First, fund the development and maintenance of networks and wraparound services designed to provide mentorship, research rotations, internships, shadowing programs, support systems, and career advancement in STEM fields, especially as they are relevant to gender, racial, ethnic, income, and geographic diversity.

Second, I recommend expanding dramatically the funding for NSF Graduate Research Fellowships and Research Experiences for Undergraduates, programs which are incredibly effective at attracting and retaining young scholars in STEM. Crafting similar programs for high school students and masters students, and post-doctoral associates is also a part of this.

Third, I recommend creating funding mechanisms that deliberately promote interdisciplinary collaboration between use-driven and curiosity-driven scholars. As a provost, with the landscape view of research at Notre Dame and across higher education, I have come to believe that the three most powerful drivers of innovation are curiosity, purpose, and profit. The Endless Frontier Act has the potential to tap deeply into all three of these drivers.

While I am proud of my research group's work to protect children, it would be vanity for me to claim credit for it. The National Science Foundation funded my graduate education, and Federal funding fuels my research. So, the credit really goes to all of you Senators, for your long-standing commitment to science and scientists.

In the 1950s, curiosity-driven researchers, who were botanists and cultural anthropologists, were fascinated by the Madagascar rosy periwinkle. Eventually, an extract of the plant was used by use-driven researchers at Eli Lilly to develop vinblastine, one of the four chemotherapeutics that was used to save my daughter Viviana's life when she was diagnosed with Hodgkin's Lymphoma 3 years ago. She is now a healthy and happy college sophomore, studying chemistry.

I provide more detailed comments in my official testimony, for the record. Thank you for the opportunity to appear before you today.

[The prepared statement of Dr. Miranda follows:]

PREPARED STATEMENT OF MARIE LYNN MIRANDA, PH.D., CHARLES AND JILL FISCHER PROVOST, PROFESSOR OF APPLIED AND COMPUTATIONAL MATHEMATICS AND STATISTICS, DIRECTOR OF THE CHILDREN'S ENVIRONMENTAL HEALTH INITIATIVE, UNIVERSITY OF NOTRE DAME

Introduction

Madam Chair, Ranking Member Wicker, and Members of the Committee, on behalf of the University of Notre Dame, I am honored to appear before you today to offer testimony regarding the Endless Frontier Act.

Chair Cantwell, as a career scientist, researcher, and higher education administrator, I am grateful for your commitment to scientific discovery and innovation, and your Committee's dedication to strengthening our Nation's innovation ecosystem. I am particularly appreciative of your efforts and leadership in creating pathways for women and other underrepresented groups to pursue STEMM (science, technology, engineering, mathematics, and medicine) fields.

I also extend greetings to my own Indiana Senator, Todd Young, who is working with Senator Schumer to author this important legislation. Thank you for your leadership and longstanding support and commitment to university research and learning.

I am particularly pleased to be here in person—something that might not have been possible a month ago, but is today due largely to the tremendous U.S. Federal government investments made over many years in basic science and technology research conducted at our Nation's universities. Those long-term, strategic investments in science and technology established the knowledge base and foundation that enabled pharmaceutical companies to develop and produce several safe, effective vaccines to combat the COVID–19 pandemic in a timespan previously unimaginable.

Background

I am a professor of applied and computational mathematics and statistics at the University of Notre Dame, where I also serve as the Charles and Jill Fischer provost and direct the Children's Environmental Health Initiative (CEHI), which is a research, education, and outreach organization committed to fostering environments where all people can prosper.

I have spent more than 30 years as a use-driven, or applied, researcher who deploys Bayesian spatial statistics to identify impacts of and solutions to environmental and social threats to children. I have applied science and technology to help understand and address complex, real-world challenges locally, regionally, and nationally.

In my own work and in my role as provost at the University of Notre Dame, I have witnessed firsthand the power of the Federal government's substantial investments in basic science and technology to improve lives for individuals, communities, and our society more broadly. That is our mission at the University of Notre Dame—*to be a force for good in the world.*

It is common to conceive of researchers dividing up into curiosity-driven versus use-driven scientists and engineers. In fact, a virtuous cycle exists between the two. Curiosity-driven researchers elucidate critical insights into basic science questions that drive new opportunities for use-driven researchers. In turn, use-driven researchers highlight new challenges for curiosity-driven researchers to take up. And in fact, many scientists and engineers are both use-driven and curiosity-driven.

While I am primarily a use-driven researcher, I rely heavily on basic science or curiosity-driven research. Use-driven researchers and curiosity-driven researchers interact constantly, discussing problems, challenging each other, and sharpening each other's work. When I wrote my dissertation, I had to use a mainframe computer to analyze the 40,000 observations in my dataset, and I could only implement the analysis at the county level. Back then, 40,000 observations was big data!

In contrast, for the past 20 years, I have worked on childhood lead exposure, specifically interested in using spatial analysis to identify houses where children are most likely to be exposed to lead, and then remediate houses to prevent future exposure. Federal investments in basic science research on geographic information systems, as well as computational power and speed, made it possible for me to analyze millions of observations on my desktop computer. In addition, new insights from theoretical statisticians made it possible to implement our models at the individual tax parcel level.

Housing departments use CEHI's detailed models to prioritize housing rehabilitation dollars, working with property owners to make homes lead-safe. Health departments use the same models to drive lead screening programs, resulting in one county, for example, experiencing a 600 percent increase in its ability to identify children with elevated blood lead levels at no additional cost.

These models have been replicated for communities across the United States. As a result, we have protected thousands of children from potential harmful effects of lead exposure, including learning and behavioral disorders, poor hearing, attention deficits, and other negative neurological effects.

While the scope of the Endless Frontier Act is broad, as requested, I will focus this testimony on opportunities to strengthen the Nation's research enterprise and increase diversity of the science, technology, engineering, mathematics, and medical (STEMM) fields.

Federally funded research: the foundation of American innovation and security

It is unfortunate that many Americans neither see nor appreciate the myriad, intricate connections between basic, curiosity-driven research and its end uses, developments, and products. Instead, many view the amazing technologies that surround us—self-driving vehicles, rovers on Mars, mobile phones that do everything from navigate our world to monitor our health—as the unexpected next new products to shape our world.

The truth, of course, is that nearly all of the technological innovations that enable our modern society emerge from a *deliberately built* foundation of federally funded research conducted *over many years* at universities or federally funded research laboratories. While many Americans may not fully appreciate this connection, our peers, competitors, and potential adversaries around the globe certainly do.

The initial large-scale investments in federally funded research were a conscious post World War II decision related to the Cold War. Other nations watched as U.S. government investments in science, sustained in part through National Science Foundation (NSF), created a global superpower and shaped a society and economy that have been the envy of the world for multiple generations. The American system awards funding *competitively,* balancing a centralized source for funding with the incredible entrepreneurial spirit that characterizes our researchers. This system aligns fully with American democratic values.

Other nations are now making similar investments with similar ambitions at a pace that exceeds the United States, especially expenditures in critically important areas such as artificial intelligence, quantum computing, and other advanced technologies. According to data from an April 2020 Congressional Research Service report, U.S. investments in research and development funding declined from 69 percent of the world's total in 1960 to 28 percent in 2018. Interestingly, the U.S. decline is not the result of cuts in U.S. investments. Rather, the decline in

U.S. global leadership in this area is the result of even greater investments by the governments of other countries that recognize the importance of R&D to their innovation and competitiveness.[1]

That targeted funding is having direct results. For example, since the mid-2000s, increased investments by China in science and technology have led to steady growth in the number of scientific journal articles published by Chinese researchers, a key measure of scientific innovation. China is now the largest single global producer of scientific journal articles, surpassing the U.S. in 2016.[2]

Education as a foundation of innovation

Sustainable economic development in general is not easy to achieve, and innovation-based economic development is an even greater challenge. However, as noted in the World Economic Forum's 2019 Global Competitiveness Report, "In most advanced and emerging economies, technology adoption and innovation have become priorities for governments and companies alike as a source of value creation, productivity growth, and improved living standards. Technology can also improve access to basic services, working conditions, health outcomes and economic security."[3] Even prior to the COVID–19 pandemic, the nature of jobs and work has been changing at a rapid pace, enabled by advances in computer science and engineering, advancements in learning sciences, and new conceptions of work and workplaces.

Linked to this rapid pace of change is an unprecedented opportunity to expand access to emerging new industries and occupations, enhance productivity and quality of work life, and increase workforce participation. U.S. regions with successful innovation-based "ecosystems" share in common well-defined links between colleges and universities, a skilled workforce, investments in technology and infrastructure, and an entrepreneurial culture that drives a region to capitalize on its economic strengths.

Moreover, America's need for both basic, curiosity-driven research and applied, use-driven research is greater than ever today because the challenges and competition we face as a society and nation are greater and more complex than ever. Our societal and technical challenges also require greater collaboration between research fields, increased diversity of perspectives and skills, and a much larger and broader

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[1] Congressional Research Service, Global Research and Development Expenditures: Fact Sheet Updated April 29, 2020. *https://fas.org/sgp/crs/misc/R44283.pdf,* 2020.

[2] National Science Foundation, Science and Engineering Indicators 2018, Outputs of SE Research: Publications, *https://nsf.gov/statistics/2018/nsb20181/report/sections/academic-research-and-development/outputs-of-s-e-research-publications,* 2018.

[3] World Economic Forum Global Competiveness Report, *http://www3.weforum.org/docs/WEF_TheGlobalCompetitivenessReport2019.pdf,* 2019.

talent pool entering STEMM fields. The Endless Frontier Act represents a major effort to address these concerns, and I commend its authors and the Committee Members for their renewed commitment to confront these challenges.

Strengthening our U.S. innovation ecosystem necessarily begins with education and efforts to encourage young Americans to pursue rigorous academic courses, and it continues with efforts to transfer technology and knowledge created in research universities to industry, which brings these innovations to the marketplace. Complementary to these technology transfer initiatives are college and university programs that support regional industry innovation, which creates jobs, boosts regional economies, and addresses regional concerns.

Thinking outside the pipe

It is popular to refer to the STEMM pipeline as a metaphor for producing a STEMM-enabled workforce. Referring to it as a pipeline, however, implies that there is only one intake point and one outtake point, with potential leaks along the way. In fact, members of the STEMM workforce travel different paths. My own research path moved from mathematics to economics to toxicology to statistics. I encourage people to think about multiple pathways, rather than pipelines.

Some paths are smooth and direct; some are circuitous and must traverse rough terrain. Some lead to STEMM PhDs and some to STEMM bachelor or associate degrees. Some have only one entry point; some have many. We need all these paths to build the STEMM enabled workforce our country needs for national security, for national competitiveness, for national prosperity, and to solve our most challenging societal problems.

While we need PhD-trained researchers to develop new cybersecurity systems, we also need people with associate and bachelor degrees trained to run those systems on a daily basis. While we need PhD-trained researchers to predict and model natural disasters, we need large STEMM-enabled multidisciplinary teams to use that research to react in real time on the ground in disaster zones.

We are also vulnerable when it comes to STEMM talent. The ability of the U.S. to meet the demand for individuals with the knowledge, skills, curiosity, and creativity necessary to enter STEMM-intensive careers is hindered by the lack of women and underrepresented minority populations in STEMM fields.

We must also think broadly about the need to bring our entire talent pool to this issue. For example, women comprise 51.5 percent of our population and 47 percent of the labor force. However, in computer science, only 19 percent of those awarded bachelor's degrees in 2016 were women—down from 27 percent in 1997.[4] Similarly, underrepresented minorities comprise 27 percent of our population and 30 percent of the labor force, but only 9 percent of those with science and engineering doctorate degrees.

Unfortunately, 39 percent of U.S. high schools are unable to offer physics, a foundational course for STEMM fields. The inability to offer physics and other science and mathematics courses relates directly to the lack of qualified teachers, primarily in low resource, smaller schools. So, nearly two in five high school graduates, regardless of their academic ability, interest, or motivation, will start college facing a much tougher path for pursuing STEMM degrees.[5]

At Notre Dame, we established a STEMM scholars program in 2018 to support students who intend to pursue STEMM careers but arrive at our university without the benefit of multiple Advanced Placement courses or other STEMM enrichment opportunities. This program has been very successful in helping these students succeed in their courses and persist in STEMM disciplines, without the emotional burden of feeling less qualified than others.

Modernizing university technology transfer programs

The Endless Frontier Act seeks to strengthen America's economic competitiveness and efficiency by producing innovative technology through research and commercialization grants. Achieving these goals will require commercialization of innovations that emerge from these research investments, much of which will go to universities.

To achieve the goals of the Endless Frontier Act, universities need to remake their technology transfer and commercialization operations. More specifically, they should shift away from the nearly ubiquitous model of relying on tech managers, who usually have deep technical knowledge and little business experience, to commercialize

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[4] National Center for Educational Statistics, *Women, Minorities, and Persons with Disabilities in Science and Engineering,* 2019.

[5] Science Education Policy, *Problematizing the STEM Pipeline Metaphor: Is the STEM Pipeline Metaphor Serving Our Students and the STEM Workforce?,* 2014.

university discoveries. Twenty years of data have shown this approach does not work.

For example, despite tens of billions of dollars spent on university research each year, 95 percent of all intellectual property discovered in universities goes unlicensed.[6] Of the intellectual property that is licensed, 72 percent takes place at only 37 universities. Furthermore, only 13 percent of tech transfer offices are self-sustaining.[7] Why? Technologies that emerge from universities are very early-stage and full of risk for potential licensees, so potential investors are hesitant to invest. Traditional tech transfer offices lack the skills and processes to de-risk a technology sufficiently enough that the right funders, founders, entrepreneurs, advisors, mentors, or corporate partners will engage.

To address this issue, university commercialization operations should put in place a rigorous and replicable de-risking process. At the University of Notre Dame, we have implemented a stage-gated, milestone driven methodology to de-risk technologies and make them more attractive for commercialization.

Implementing such a process drives success in a number of ways. First, it allows the commercialization office's staff to specialize in key areas, including IP and technology, business, and startups. Second, it ensures the staff applies the right resources in the right amounts at the right times for the right projects. Finally, it turbocharges the speed with which technologies move from discovery to market.

Over the past five to eight years, a small number of universities have started using a variant of this system and the results are impressive. They have created hundreds of startups, tens of thousands of jobs, and billions of dollars in value. Research funding alone will not achieve the goals of the Endless Frontier Act. New and inventive commercialization processes will be required.

Expanding innovation at the national, state, and regional levels

U.S. business research and development activities are presently concentrated in a relatively small number of states. In 2018, of the $441 billion in R&D performed in the U.S., most went to California (33 percent), followed by Washington (7 percent), Massachusetts (6 percent), Michigan (5 percent), Texas (5 percent), New Jersey (5 percent), New York (4 percent), Illinois (3 percent), and Pennsylvania (3 percent).

While the particular focus of EFA legislation is to address and advance America's national security and global competitiveness, I applaud its efforts to provide targeted investments and development of additional, broadly distributed technology hubs or centers throughout the United States, including in promising "Heartland America" places like Indiana. Indiana is well positioned to serve as one of these state tech hubs, as we have rich collaborations across the three major research universities; Purdue University, Indiana University, Notre Dame, and with the Crane Naval Surface Warfare Center and the Indiana State government's Indiana Economic Development Corporation (IEDC). We also have a highly active organization coordinating the corporate relationships in the State, the Central Indiana Corporate Partnership (CICP). The CICP has become a major catalyst for growing the industrial competitiveness of the companies in the State in areas such as (see list of EFA foci). In fact, a recent report that we commissioned from the Brookings Institution identified existing strengths and related opportunities in a manner that is generally consistent with the tech hub framework.

As of 2019, Indiana has the Nation's third-highest rate of employment in these R&D and STEMM-worker intensive industries. Indiana's advanced industries employ 10.5 percent of the Hoosier workforce (323,600 individuals), while producing 25 percent of the state's GDP and 60 percent of the state's exports. And because of long supply chains and multiplier effects, the state's industries are indirectly responsible for another 700,000 jobs.

Our state's advanced industry mix makes clear that Indiana's economy is largely driven by advanced manufacturing. Among Indiana's advanced industry workers, 76 percent are employed in advanced manufacturing. These workers produced 79 percent of the state's advanced industry output—amounting to roughly 20 percent of the state's contribution to GDP.[8] Furthermore, the life sciences are a particularly significant contributor to the state's advanced manufacturing sector. Specifically, pharmaceutical and medical device production together employ almost 15 percent of

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[6] Nature: *https://www.nature.com/news/universities-struggle-to-make-patents-pay-1.13811,* 2013.

[7] AUTM (formerly the Association of University Technology Managers) Report, *https://autm.net/surveys-and-tools/databases/statt,* 2019.

[8] Indiana GPS Project Report, *https://indianagpsproject.com/,* 2021.

all Hoosier advanced manufacturing workers and are responsible for more than 25 percent of all Hoosier advanced manufacturing output.

The South Bend–Elkhart (SBE) Region is at the locus of three emergent trends within the global economy: the shift to a digital environment in industry; the growing polarity of innovation and investment; and the renewed emphasis on applied and experiential learning models to better equip the future workforce.

While these developments present potential challenges, they also signal opportunity. The growth of wireless technologies, artificial intelligence and robotics, data analytics, and digital sensor technologies—often referred to as the fourth industrial revolution—have accelerated the pace of innovation and increased the need for highly skilled expertise.

Companies that succeed in this transition will be, first and foremost, enterprises still producing tangible products, but doing so within a data-based, digital environment with connectivity from the shop floor through the supply chain and customer base. Regions at the forefront of digital transformation, in turn, offer some of the most compelling career and economic opportunities for a well-trained workforce, thereby concentrating talent, investment, and innovation.

In response to these emerging economic demands and need for a coordinated solution, funded by a $42 million grant from the Lilly Endowment, Notre Dame and the South Bend Elkhart Regional Partnership launched the LIFT Network and iNDustry Labs to more effectively and proactively serve the businesses in the South-Bend Elkhart region with a regional innovation hub. The LIFT Network and iNDustry Labs link the faculty expertise, student talent, and R&D capabilities at the University and throughout the region with the regional companies embarking on the digital transformation journey to become more productive, resilient, and skilled organizations in the digital economy.

Recommendations

I offer the Committee seven recommendations to create greater access to STEMM pathways, to promote increased collaboration between and among curiosity-and use-driven researchers, and to ensure the full potential of the Endless Frontier Act is achieved.

1. Create funding mechanisms that encourage research institutions to collaborate with middle schools and high schools *at scale,* including supporting the professional development of middle and high school science teachers, developing innovative STEMM curricula, and inviting students for meaningful STEMM on-campus experiences. Separately fund a full-scale analysis of the effectiveness of different approaches.
2. Seed fund the development of wrap-around services for first-generation students and those from low resource backgrounds to ensure they can prosper in STEMM fields. Separately fund a full-scale analysis to assess effectiveness of different interventions, preferably as randomized controlled trials.
3. Fund the development and maintenance of networks designed to provide mentorship, research rotations, internships, shadowing programs, support systems, and career advancement in STEMM fields at all levels, especially as they are relevant to gender, racial, ethnic, income, and geographic diversity.
4. Dramatically expand funding for NSF Graduate Research Fellowships (GRFs) and Research Experiences for Undergraduates (REUs), programs that are incredibly effective at attracting and retaining young scholars in STEMM. Craft and fund similar programs for high school students and masters-level students.
5. Create funding mechanisms that promote collaboration between researchers in different fields and between use-driven and curiosity-driven scholars. These mechanisms should also include grants designed specifically to develop the databases that will accelerate use-driven research.
6. Provide funding that extends the length of current grants to address the impacts of COVID-19 on research. Such funding is critical for keeping women and minority scholars in STEMM.
7. Implement funding incentives to help universities transform their tech transfer offices into business-oriented, de-risking operations that better promote commercialization of federally funded research.
8. To maximize the return on Federal investments in regional technology hubs, consider regional readiness, including vibrancy of partnerships, existing structures for university-industry partnerships, and local/regional support in workforce development programs.

Conclusion

Keeping our Nation secure, prosperous, and economically competitive in a dynamically changing world depends upon a tremendous investment in science and technology research. That investment is a necessary one, and it is one our peers, competitors, and adversaries are making. That investment will also allow us to address our most pressing societal challenges and continue to fulfill the great promise of the American experiment. Our generation must make this commitment, as previous generations did for us, to secure a prosperous future for our children and grandchildren.

As a university provost, with a landscape view of research at Notre Dame and across higher education, I have come to believe that the three most powerful drivers of innovation are curiosity, purpose, and profit. The Endless Frontier Act has the potential to tap deeply into all three of these drivers.

While I am proud that my research group's work has helped protect children across the country from lead exposure, it would be vanity for me to take credit for those impacts. The National Science Foundation funded my graduate education, and Federal funding fuels my research. So the credit really goes to all of you, senators, and to your colleagues in the House of Representatives, for your longstanding commitment to science and scientists.

I will close with a personal story of the powerful synergy between curiosity-driven and use-driven research, the role of commercialization, and a single, but important, good outcome.

In the 1950s, curiosity-driven botanists and cultural anthropologists were fascinated by the Madagascar rosy periwinkle. Eventually, an extract of the plant was used by Eli Lilly to develop vincristine, a chemotherapeutic that increased the survival rate from childhood leukemia from 10 to 90 percent. From the same plant, they also developed vinblastine, one of the four chemotherapeutics that was used to save my daughter Viviana's life when she was diagnosed with Hodgkin's Lymphoma three years ago. She is now a healthy and happy college sophomore, *studying chemistry.*

Again, I commend this Committee for their dedication to this effort and thank you for the opportunity to testify today.

Chair CANTWELL. Thank you, Dr. Miranda. Thank you for sharing that personal story, thank you. It makes it very meaningful today, thank you.

Dr. Shaw, thank you so much for joining us.

STATEMENT OF DR. DAVID SHAW, PROVOST AND EXECUTIVE VICE PRESIDENT, MISSISSIPPI STATE UNIVERSITY

Dr. SHAW. Thank you. Chair Cantwell, Ranking Member Wicker, members of the Committee, thank you for the opportunity to speak to you today about a topic that is vital to our Nation's future. For the past century, the U.S. has led the world in research, and technology development. However, that leadership is now in peril, requiring immediate and sustained action. This issue has no political nor geographic affiliation, and solutions must be crafted that benefit every American, if we are to maintain that leadership. We must be unified in developing this solution, since our threats are not within the United States; rather the threat is from competition abroad.

Past Federal investments in research have made a tremendous difference in my home state of Mississippi. Mississippi State University won a National Science Foundation Engineering Research Center in 1990, focused on computational field simulation. As a part of the incentive to attract Nissan to the state, we leveraged the ERC to create a new Center for Advanced Vehicular Systems at our university. The Department of Commerce has now estimated the impact of just this one center, to be nearly $6 billion over a 12-

year period, in jobs saved and created. Without the NSF investment, this simply would not have been possible.

I appreciate the language in the current legislation that recognizes the need for broad participation, but I also believe it does not go far enough. The Established Program to Stimulate Competitive Research, EPSCoR, is mentioned specifically. I serve on the EPSCoR Coalition board and can attest, from firsthand knowledge, that this program has a substantial impact on the 28 states and territories that qualify for this program. However, allocating only 12 percent of the funds to the EPSCoR program belies the commitment to see distribution of technology and innovation funding beyond the five states that see the vast majority of existing funds. Language regarding the regional hubs, similarly, has a minimal role for an EPSCoR state to be included, and no leadership role is expected. EPSCoR jurisdictions are the home of tremendous potential. However, a lack of resources greatly limits the development of this potential.

The disparity of existing NSF funding between states, the haves and have-nots, is striking, and my concern is that without specific and proactive action mandated in legislation this disparity will only worsen. Congress has the opportunity to ensure that zip code does not determine whether talented students can develop the workforce of the future, the new ideas for entrepreneurial businesses, and the economic development so desperately needed in some of our more depressed economies.

I will use my state and my institution as an example. Mississippi's population has the highest percentage of African Americans of all U.S. states. At MSU, we enroll a higher percentage of African Americans, by a wide margin, than any other university in the Southeastern Conference. And by an equally wide margin, MSU enrolls a greater proportion of African Americans than any other historically white land-grant university in the entire United States. MSU also enrolls the most PELL-eligible students of any university in our state. We strive for all students, but particularly those from underrepresented and disadvantaged populations, to be successful. To do that, however, we must be provided the resources to involve these students in creative discovery, technology development, and entrepreneurship to ensure that they are given all of the tools necessary to be successful in their lives and careers. Currently, Mississippi ranks at the bottom of all states in terms of NSF funding per capita. Less than $7 is invested per Mississippi citizen, whereas the national average is $23, and in some states is over $80 per capita. This inequity simply must be addressed if we as a nation are to move forward in unity.

Two years ago, I had the opportunity to testify at a sub-committee hearing before this Committee and would reiterate here the following four recommendations from that testimony, calling for investments to be, first, broad-based geographically. Second, truly trans-disciplinary in nature. Third, broadly supportive of both fundamental and developmental research endeavors. And finally, encouraging Federal, State, university, and industry partnerships.

Chair Cantwell, Ranking Member Wicker, members of the Committee, I thank you again for the opportunity to testify before you today. Mississippi State University is a staunch advocate for bipar-

tisan support in technology development and innovation, and we are eager to be full participants in the efforts. Thank you.

[The prepared statement of Dr. Shaw follows:]

PREPARED STATEMENT OF DR. DAVID SHAW, PROVOST AND EXECUTIVE VICE PRESIDENT, MISSISSIPPI STATE UNIVERSITY

Chair Cantwell, Ranking Member Wicker, and members of the committee, thank you for the opportunity to speak to you today about a topic vital to our Nation's future. For the past century the U.S. has led the world in research, innovation, and technology development. However, that leadership is now in peril, requiring immediate and sustained action. This issue has no political nor geographic affiliation, and solutions must be crafted that benefit every American if we are to maintain that leadership. We must be unified in developing this solution, since our threats are not within the U.S.; rather the threat is from competition abroad.

Past Federal investments in research have made a tremendous difference in our state. Mississippi State University (MSU) won a National Science Foundation (NSF) Engineering Research Center (ERC) in 1990, focused on computational field simulation. We have many success stories that came from that ERC, but none more important than how it was used to attract Nissan to the State of Mississippi. As a part of the incentive to attract Nissan, we leveraged the ERC to create a new Center for Advanced Vehicular Systems (CAVS) at MSU, with a combination of basic engineering research and industrial outreach to support the automotive industry in the state. In fact, the Department of Commerce has estimated the impact of just this one center, not the entire university, to be nearly $6 billion over a twelve year period, in jobs saved or created. Without the NSF investment, I doubt any of this would have been possible.

I appreciate the language in the current proposed legislation that recognizes the need for broad participation, but would challenge that it does not go far enough. The Established Program to Stimulate Competitive Research, EPSCoR, is mentioned specifically. I serve on the EPSCoR Coalition board, and can attest from firsthand knowledge that this program has a substantial impact on the 28 states and territories that qualify for this program. However, allocating only twelve percent of the funds to the EPSCoR program belies the commitment to see distribution of technology and innovation funding beyond the five states that see the vast majority of existing funds. Language regarding the regional hubs similarly has a minimal role for an EPSCoR state to be included, and no leadership role is expected. EPSCoR jurisdictions are the home of tremendous potential; however, a lack of resources greatly limits the development of this potential.

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I will use my state of Mississippi and my institution as an example. Mississippi population has the highest percentage of African Americans of U.S. states. At MSU, we enroll a higher percentage of African Americans—by a wide margin—than any other university in the Southeastern Conference. And by an equally wide margin, Mississippi State enrolls a greater proportion of African Americans than any other historically white land-grant university in the United States. MSU enrolls the most PELL-eligible students of any university in our state. We strive for all students, but particularly those from under-represented and disadvantaged populations, to be successful. To do that, however, we must be provided the resources to involve these students in creative discovery, technology development, and entrepreneurship in order to ensure that they are given all the tools necessary to be successful in life and their careers. Currently, Mississippi ranks at the bottom of all states in terms of NSF funding per capita. Less than $7 is invested per Mississippi citizen, whereas the national average is $23, and in some states is over $80 per capita. This inequity simply must be addressed if we as a nation are to move forward in unity.

On another note, we need to see stronger coordination with other Federal research agencies and national laboratories. In working with Department of Energy and Department of Defense national labs, it has often struck me that there needs to be a much stronger partnership among Federal agencies in technology and innovation. Discovery science at the national labs can readily partner with technology development programs at academic institutions that would benefit both, and dramatically enhance innovation and entrepreneurship in the U.S. Mississippi State has done

this particularly well with the U.S. Army Corps of Engineers, Engineer Research and Development Center in Vicksburg Mississippi, and our state has seen tremendous benefit from this partnership.

Establishing a Technology and Innovation Directorate at NSF will not only ensure the United States' leadership role in research is continued, it will also bring about STEM training for the workforce of the future and lead to an economic development renaissance not seen in decades. Mississippi State has placed tremendous focus on these efforts already, and the benefits have been gratifying. Our Thad Cochran Research, Technology and Economic Development Park is completely filled, and phase 2 has already been implemented. We have wonderful, entrepreneurial industry partners such as Camgian, Babel Street, II–IV Inc, Martin Federal, and HBM nCode working side by side with MSU faculty and students in efforts to grow the Mississippi economy. Our Center for Advanced Vehicular Systems works particularly closely with industry in the state to develop innovative solutions as businesses grow. And, our Raspet Flight Research Laboratory has a seven-decade history of partnering with companies such as Boeing, Airbus, and new startup companies in manned and unmanned aircraft systems. It is clear that these partnerships are having a positive impact on the community, pushing it to a leading technology center with new jobs and industries.

Two years ago I had the opportunity to testify at a sub-committee hearing before this Committee, and would reiterate here the following four recommendations from that testimony, calling for investments to be:

1. Broad-based geographically. We must support the best and brightest students and researchers wherever they are, not just at a few locations if we as a nation are to make the progress you envision.
2. Trans-disciplinary in nature. The most challenging issues we face today cannot be solved by any one or even a few disciplines. Rather, issues such as health disparity, food security, and water scarcity can only be solved by the hard sciences and social sciences working together in new and novel ways.
3. Broadly supportive of both fundamental and developmental research endeavors. Both basic and applied research are critical if we are to lead the world in innovation and entrepreneurship.
4. Encouraging federal, state, university, and industry partnerships. We must find ways to invest in research that leads directly to innovation that spawns entrepreneurship and economic development in the private sector. Historically, our economy is based on this innovation, and with reduced private investment in academic research, Federal funding is ever more important if we are to continue to lead the world.

Finally, I applaud your efforts to ensure that the U.S. is working on an even playing field in research and development. MSU fully recognizes the threat from intellectual property theft, as well as national security issues in research, and diligently works with Federal law enforcement officials to do all that we can to ensure our research findings are held with the appropriate confidentiality.

Chair Cantwell, Ranking Member Wicker, members of the committee, I thank you again for the opportunity to testify before you today. Mississippi State University is a staunch advocate for bipartisan support in technology development and innovation, and we are eager to be full participants in your efforts.

Chair CANTWELL. Thank you, Dr. Shaw. Thank you for representing Mississippi State by being here and testifying. I think your contributions to this discussion are very important, so thank you.

We are now going to turn to Linden Rhoads, who is joining us virtually.

STATEMENT OF LINDEN RHOADS, GENERAL MANAGER, THE W FUND

Ms. RHOADS. Good morning. My name is Linden Rhoads, and I am testifying today from Seattle, Washington, where it is allergy season, and this morning I am inconveniently afflicted. So, I apologize for that.

Thank you, Senator Cantwell, for the opportunity to share my experience that I hope shows that, with adequate funding from Congress, universities can better provide for innovation for our Nation.

From 2008 to 2014, I served as the Vice Provost for Commercialization for the University of Washington. During my tenure, the university agreed to a substantial temporary increase of the budget for tech transfer, which we used to implement an integrated slate of programs designed to radically increase licensing and spin-out activity. So, my experience is a reinforcing data point for those of you who posit that there is gold in the academic research hills, and that we could, as a nation, be mining more of it.

The University of Washington has a massive research enterprise, conducting over $1.5 billion of mostly federally funded research every year. Yet, as with most research universities, there had not been enough to show for it in commercialization output. When I arrived, the 10-year run rate for spinouts from the university was 8 per year, mostly as small hobby businesses. In my last year at UW, we spun out 21 companies, which put UW at third in the Nation for academic spinouts, with the majority of those companies being venture capital appropriate companies that had the potential to scale, create numerous jobs for our State, and have real impact on society.

I was not a career academic executive. I am a serial technology entrepreneur and venture investor, who was hired to be a change agent. And I made a multitude of programmatic changes over 6 years. We brought in in-house patent agents, in both IT and life science, who were available to confer free of charge with research faculty about IP in areas in which they were considering writing research grants, seeking promising IP white space.

We launched an entrepreneur-in-residence program to provide broad mentorship to entrepreneurial faculty and introduced highly technical potential CEOs with subject-matter expertise to our world class researchers.

We established advisory boards of industry experts to advise life science faculty on reimbursement, clinical trial design, and the FDA. In many cases, the only way our faculty entrepreneur teams could spin-out a life science startup was with an SBIR grant. So, we hired an SBIR grant writer.

We awarded a million dollars annually in $50,000 commercialization grants to the most promising translational projects. For some steps, that would reduce technical or market risk and increase the likelihood that the project could attract for-profit investors.

We launched the university's first incubator, a building with wet lab space, as well as office space for startups. We raised a $20 million venture fund, The W Fund that invested exclusively in spinouts from Washington State's non-profit research institutions.

I still serve as the General Manager of The W Fund, as Senator Cantwell mentioned. And we are making our last investment, a follow-on investment in one of our 19 portfolio companies, this week. Expert sector-specific mentorship, value-creating gap funding, and strong IP support created significant new opportunities and economic success out of UW's already stellar research enterprise. This level of support is necessary because university researchers balance

commercialization efforts with their academic teaching and research workload.

And the programs I have mentioned require funding. Very few tech transfer offices, especially those at public universities, have adequate funding. UW happens to have had one big tech transfer hit, the Hall patents that provided a base level of funding to its tech transfer office. I convinced the university administration to invest over $2 million, closer to 3, more dollars per year while I was there to allow us to spend more on the programs I have mentioned, as well as a bump in patent activities. It was a happy coincidence that this public university was positioned to accede to my request.

My successor started when the Hall patents had just expired and spent 5 years winding down many of the programs that had yielded great results. Support of the innovation ecosystem is a long-term play and, while short-term gains can be achieved, game-changing potential is lost for our Nation when programs must be dismantled. And that is because administrators are wary of programs that suggest that minimal capital investments will have great results, or that significant capital investments, for only a few years, will have sustained results.

Too often government or foundations offer universities less than a million dollars a year, for one to 3 years, with the notion that after the funding ends, the programs they funded will somehow become self-sustaining. What is ideally needed is a 10-year commitment that the substantial funds major tech transfer offices need to provide comprehensive innovation support, including the funds to speculatively protect the intellectual property generated by federally funded research, including filing international patents where appropriate.

Only a few elite, private institutions can afford to do this adequately today. All of the above has at least a $3 million price tag per $1 billion of federally funded research per year, on top of the funding such offices currently have available in their budget for base operations. But I believe that the results would make that investment nation changing. And I would be happy to answer any questions about that.

Thank you so much for the invitation to participate today.

[The prepared statement of Ms. Rhoads follows:]

PREPARED STATEMENT OF LINDEN RHOADS, GENERAL MANAGER, THE W FUND

Good morning,

My name is Linden Rhoads, and I am testifying today from Seattle Washington. I've been asked to participate because from 2008 to 2014, I served as the Vice Provost for Commercialization for the University of Washington. During my tenure the university agreed to a substantial temporary increase of the budget for tech transfer, which we used to implement an integrated slate of programs designed to radically increase licensing and spin-out activity, and we were successful. So my experience is a reinforcing data point for anyone who posits that there is gold in the academic research hills, and that we could as a nation be mining more of it. The University of Washington has a massive research enterprise, conducting over $1.5B of mostly federally funded research every year. Yet, as with most research universities, there had been little to show for it in commercialization output when I arrived; the ten year run rate for spin-outs from the university was 8 per year, and many of these were companies destined to be small hobby businesses. In my last year at UW we spun out 21 companies—that put UW at third in the Nation for academic spin-outs—with the majority of those companies being venture capital appropriate companies that had the potential to scale, create jobs, and have real impact. I was not

a career academic executive. The UW hired in me a serial technology entrepreneur two of whose start-ups had been spin-outs from the university's computer science and engineering department. I was hired to be a change agent, and we made a multitude of programmatic changes that drove the spectacular improvement in results over the 6 years I ran the office. We brought in in-house patent agents with specialization in both IT and life science who were available to confer free of charge with research faculty about IP in areas in which they were considering writing research grants, seeking promising "IP white space." We launched an entrepreneur-in-residence program that provided broad mentorship to entrepreneurial faculty and would-be entrepreneurial faculty, and introduced potential CEOs with industry and highly technical and scientific subject matter expertise to our world class researchers. We created advisory boards of industry experts who could advise our life science faculty on regulatory issues, clinical trial design, and the right approach to the FDA. Because in many cases the only way our faculty/entrepreneur teams could amass sufficient capital to spin-out a life science start-up was with an SBIR grant, we hired an SBIR grant writer to assist us in doing a better job of garnering that support. We awarded $1.25M *annually* in $50K "commercialization" grants to the most promising translational projects, requiring that the funds be used not necessarily for science, but for some step that would reduce technical or market risk and thus increase the likelihood that the project could attract ROI funding from for-profit investors. We launched the university's first incubator, a building with wet lab space as well as office space for start-ups. We raised a $20M venture fund, The W Fund, that invested exclusively in spin-outs from Washington's non-profit research institutions. I still serve as the General Manager of The W Fund and we are making our last investment, a follow-on investment in one of our 19 portfolio companies, this month. Expert sector-specific mentorship, value-creating gap funding, and strong IP support created signficiant new opportunities and economic success from UW 's already excellent research enterprise. This level of support is necessary is required because university researchers balance commercialization efforts with their academic teaching and research workload. The programs I've mentioned required some level of ingenuity and passion for the business of seeing the research that has consumed $20M of Federal funding and the lives of three star researchers actually get to a patient and improve their health. But these programs also required *funding.* Very few tech transfer offices, especially those at public universities, have adequate funding. UW had had one big tech transfer hit, The Hall patents, that provided a base level of funding to the tech transfer office. I convinced the university administration to invest over $2M more *per year* while I was there to allow us to spend more on the programs I've mentioned as well as patent activities. It was a happy coincidence that my arrival coincided with a moment when this public university was positioned to accede to this request. My successor started when the Hall patents had just expired, and spent 5 years winding down many of the programs that had yielded great results. Support of the innovation ecosystem is a long-term play and whole short-term gains can be achieved, game-changing potential is lose when programs must be dismantled and rebuilt with changing budgets. This is why tech transfer administrators are wary of programs that suggest that minimal capital investments will have great results, or that significant capital investments over only a few years will have sustained results. Too often government or foundations offer universities a few hundred thousand dollars to a million dollars a year for one to three years with the idea that somehow after the program funding ends, the program will be self-sustaining. The continual pivoting and change is not helpful. What is needed is ideally a ten-year commitment of the substantial funds major tech transfer offices need to provide comprehensive innovation support including the funds to *speculatively* protect the intellectual property generated by federally funded research, including filing international patents where appopriate. Only a few elite private institutions can afford to do this adequately today. This is probably a $2.5M price tag per $1B of federally funded research per year, on top of the funding such offices currently have available in their budget for base operations. Such funding would allow universities to align their considerable tech transfer talent with entrepreneurs and investors in bridging the gap between promising discovery research and life-improving technologies and products. I'd also like to commend the iCorps HUBS. My colleagues in tech transfer continue to laud these that train researchers to pursue customer directed discovery and to focus on the end user, and that encourage well managed expert industry mentorship. *I'd be happy to answer any questions.*

Chair CANTWELL. Thank you, Linden, and thank you for the leadership at the University of Washington and your success there.

I do think it really is a very instructive case about large research institutions and what they can do on tech transfer.

So, next we are going to turn to an entrepreneur himself, who is going to explain exactly why this R&D investment is so necessary. Welcome, Dr. Gary Butler, and I would love to hear your testimony. Thank you.

STATEMENT OF DR. GARY D. BUTLER, CHAIRMAN AND CEO, CAMGIAN

Dr. BUTLER. Thank you. Good morning, Chair Cantwell, Ranking Member Wicker, and members of the Committee. Thank you for the opportunity to testify today. In my previous career, I worked here in the Beltway as an engineer for a Cambridge, Massachusetts based advanced technology firm, leading programs funded by agencies such as DARPA. In 2006 I decided to move to Mississippi, my home State, where I founded Camgian.

Since that time, Camgian has grown into an award-winning technology company, which today is building automation and data science technologies that support our military and some of the world's leading financial institutions. This from a high-tech company headquartered in a state with a greater than 20 percent poverty level.

As today's discussions reflect on the innovation needed to maintain our global leadership, I will use my time to focus on an area that I believe is vital to our country's future. This is Artificial Intelligence. Make no doubt, the U.S. is in a global race in AI. Efforts by our competitors to increase funding for AI development have resulted in a rise of new technologies that are radically transforming the battlefield. As such, Camgian is engaged in developing a new generation of AI powered military technologies that aim to provide our war fighters the capability to think and act faster than our adversaries.

To address the emerging threats to our national security and competitiveness, I applaud Congress for taking the bold move to expand the NSF to include applied research. But would ask that you consider the vital role that small tech companies play in commercialization.

Given our skills in product development and marketing, agile tech companies would bring the requisite capabilities to the NSF, to deliver leading edge technologies to market. This would also include establishing the framework for protecting our country's valuable intellectual property. To this point, one of the breakthroughs in AI is deep learning, which was created almost entirely through academic research in the United States, Canada, and the United Kingdom. Such capabilities derived from AI research are shared openly across the globe and, today, underpin many of the AI technologies that directly compete against the United States, commercially and militarily. Quoting from the book *AI Super-Powers,* "The West may have sparked the fire of deep learning, but China will be the biggest beneficiary of the heat the AI fire is generating."

So, I would like you to consider three takeaways from my testimony today. First, I would recommend the DARPA applied research model, which is proven and would provide small high-tech companies the ability to directly apply to the NSF for grants to

support technology development. Expanding investment in the NSF without an effective commercialization process, will have a minimal effect on U.S. global competitiveness. According to the National Science Board, academic institutions accounted for only 2 percent of the patents granted in 2016, and many generate less revenue from licensing their inventions than the cost of managing them, according to the *Washington Post.*

This is not meant to be a criticism of universities, but to highlight that moving research from the lab to the market is complex and is best suited for America's small high-tech sector who has the technical talent, organizational infrastructure, and business processes to fill this role immediately. Most importantly, America's small-tech entrepreneurs will bring the sense of urgency, competitive drive, and speed necessary to meet the accelerated pace of the emerging challenges to our global technical leadership.

Second, I would call on Congress to develop policy that ensures inclusivity of the entire country, not just the traditional tech-hubs, in a unifying mission that leverages the power of our Nation's diversity. This includes the diversity of thought, culture, and socioeconomics that exists across our great country to build the next generation technologies, products, and workforce of 21st century America.

Finally, history shows that if you give the U.S. entrepreneurs the mission and funding, the U.S. will win this race. Thank you.

[The prepared statement of Dr. Butler follows:]

PREPARED STATEMENT OF DR. GARY D. BUTLER, CHAIRMAN AND CEO, CAMGIAN

Good morning. Chair Cantwell, Ranking Member Wicker, and distinguished Members of the Committee, thank you for the opportunity to testify today. In my previous career, I worked here in the Beltway for a Cambridge, Massachusetts-based advanced technology research and development firm, leading applied research programs funded by organizations such as DARPA. In 2006 I made the decision to move to Mississippi, my home state, where I founded Camgian. My objective was to leverage our organic talent to build a leading high-tech company and limit the brain drain from our state, which we have done.

Since that time, Camgian has grown into an award-winning high-tech company, which today is building solutions addressing our country's most pressing national security issues and providing information products and services to some of the world's leading financial institutions. Our business model is built on artificial intelligence (AI) and software and their combined ability to drive new levels of decision automation. This from a high-tech company headquartered in a state with a greater than 20 percent poverty level and a county classified as "at-risk" by the Appalachian Regional Commission where a portion of the county is classified as economically distressed, and in the bottom 10–25 percent economically of all counties in the United States.

As today's discussions reflect on the innovation needed to maintain our global leadership, I will use my time to focus on a technology area identified in the Endless Frontier Act that I believe is vital to our country's future. This technology is AI. Make no doubt, the U.S. is in a global AI race. In July 2017, the State Council of China released a plan to build a domestic AI industry worth nearly $150 billion with a target to become the leading AI power by 2030. Global efforts to increase funding and government-led support of AI technology development have resulted in an increase in new high-tech companies and applications that are radically transforming the battlefield. As such, Camgian is deeply engaged in addressing these emerging threats by developing AI-enabled solutions that help our warfighters think and act faster than our competitors.

The primary source of our funding is from the Department of Defense (DoD). This funding supports our applied research and development efforts, which in turn fuels our technology and product development. I want to leverage our know-how, processes, technologies, and talent to address *national competitiveness issues* in AI and

expand our business in the broader commercial market. However, funding sources and opportunities to pursue this strategy for small high-tech companies like Camgian are extremely limited.

To address this critical gap, I applaud Congress for taking the bold move to expand the scope of the National Science Foundation (NSF) to include applied research in the organization's mission but would ask that you consider the vital role that high-tech entrepreneurial companies play in technology commercialization. Speaking on behalf of this community, I would advocate for an implementation plan to facilitate a public-private partnership between our country's best academic minds and our best high-tech entrepreneurs.

Applied to our national competitive gaps, this approach would catalyze those on the front lines of our global technology competition, the high-tech entrepreneurial companies. As an agile high-tech business, our advantage is speed. We cannot survive by being distracted, complacent, cautious thinkers, or incrementalists. Innovation and a sense of urgency must be in our DNA or we die at the hands of large corporations. Coupled with our skills in product development and marketing, a strong academic and entrepreneurial high-tech sector partnership would deliver future technologies and applications to the market to address our national competitive gaps.

More importantly, a prominent role for small high-tech businesses would establish the framework for protecting our country's valuable intellectual property. To emphasize the importance of this point, one of the breakthroughs in AI is deep learning, which was created almost entirely through academic research in the United States, Canada, and the United Kingdom. Capabilities derived from AI research are shared across the globe through the open-source community and deep learning technologies now underpin many products and systems that directly compete against the U.S. both commercially and militarily. Quoting from the book *AI Super-Powers* by Kai-Fu Lee, "The West may have sparked the fire of deep learning, but China will be the biggest beneficiary of the heat the AI fire is generating." [1]

In closing, I would like you to consider three takeaways from my testimony today.

First, I would recommend using the DARPA applied research model, which is proven and would provide small high-tech companies the ability to directly apply to the new NSF for grants to support technology development and prototyping. Expanding investment in the NSF without an effective commercialization process will have a minimal effect on U.S. global competitiveness. According to the National Science Board, academic institutions accounted for only 2 percent of the patents granted in 2016 and many generate less revenue from licensing their inventions than the cost of managing them, per a 2020 Washington Post article [2]. This is not meant to be a criticism of universities, but to highlight that moving research from the lab to the market is complex and is best suited for America's small high-tech sector who has the technical talent, organizational infrastructure, and business processes to fill this role immediately. Most importantly, America's high-tech entrepreneurs will bring the sense of urgency, competitive drive, and speed necessary to meet the accelerated pace of the emerging challenges to our global technical leadership.

Second, I would call on Congress to develop policy that ensures inclusivity of the entire country, not just the traditional tech-hubs and large tech firms, in a unifying mission that leverages the power of our Nation's diversity. This includes the diversity of thought, culture, and socioeconomics that exists across our great country to build the next-generation technologies, products, and workforce of 21st century America.

Finally, history shows that if you give the U.S. entrepreneurs the mission and funding, the U.S. will win this race.

Chair Cantwell, Ranking Member Wicker, and Members of the Committee, thank you again for the opportunity to testify before you today. On behalf of Camgian and other high-tech small businesses across America, bipartisan solutions with legislation such as this are essential as a catalyst to maintain the U.S. as a global technology and innovation leader.

Chair CANTWELL. Thank you, Dr. Butler. I applaud your enthusiasm and dedication, and I am certainly very interested in asking

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[1] Kai-Fu Lee, Ai Superpowers: China, Silicon Valley, And The New World Order (Houghton Miffin Harcourt Company, 1st Edition, September1, 2018) page 12

[2] John Markus (January 17, 2020) *Think universities are making lots of money from inventions? Think again.* Washington Post *https://www.washingtonpost.com/local/education/think-universities-are-making-lots-of-money-from-inventions-think-again/2020/01/16/3989e448-362f-11ea-bb7b-265f4554af6d_story.html*

questions about workforce opportunities and partnerships in Mississippi, when we get to the Q&A.

Last, but certainly not least, is the Senior Director of MIT's Office of Digital Learning, Mr. Bill Bonvillian, and he is joining us remotely.

STATEMENT OF WILLIAM B. BONVILLIAN, SENIOR DIRECTOR, SPECIAL PROJECTS, MIT OFFICE OF OPEN LEARNING AND MIT LECTURER

Mr. BONVILLIAN. Thank you, Senator. Senators Cantwell, Wicker, members of the Committee, thank you for the opportunity to talk with you today. I study and teach science and technology and have authored books, over the last few years, on workforce education, advanced manufacturing and the DARPA model. So, I wanted to step back a bit for some bigger picture discussions this morning.

U.S. technology history is littered with technologies that are innovated here in the U.S., that did not scale-up here, and were produced elsewhere. Flat panel displays, LED lightings, solar panels, lithium-ion batteries, drones, the list goes on. We know that a series of new, oncoming technologies, many listed in this bill, will be critical to our economic future. Will we make them here? And then, if the technologies are designed here and produced elsewhere, it means we are not translating the gains of innovation into our own economy.

We are now facing a great technology challenge, really for the first time, from competitor nations to our innovation capability. The consequences are going to affect our economic security, our national security, and our living standards. So, what happened to U.S. production? We are running over all trade deficit and manufactured goods of some $800 billion, an unheard-of level. We ran a trade deficit in advanced technology products, of $133 billion in 2019. Our share of global manufacturing output declined from 25 percent in 2005, to 16 percent in 2018. We lost one-third of manufacturing jobs between 2000 and 2010, with only limited recovery since then. How did this happen?

So, during World War II, the U.S. developed mass production to a level that was the envy of the world and enabled our success in that war. At the end of the war, when we were creating our R&D system, manufacturing was not the problem. We were kings of world manufacturing. We were concerned with science. We were not the science leaders going into the war, but we built remarkable science during the war and we wanted to keep it. So, when we organized R&D, we focused on science. So, we developed new science and technology advances. We did not focus on how to make them.

But production needs to be seen as part of that innovation process. Production involves deep engineering to get to a design of the technology to meet market prices and market demands, that often requires rethinking the science to get there. Manufacturing, particularly of the new technology, is a very creative stage.

Now, Germany and Japan, in the post war, they had to revive their economies, restore their industrial bases, get their people working. They did manufacturing-led innovation. Japan had to teach us about quality production in the 1980s because we had missed it. Germany's innovation is also organized within produc-

tion. It is running the largest surplus in manufactured goods ever, pays its manufacturing workers 60 percent more than the U.S. pays its manufacturing workers, and Korea, Taiwan, and China have followed that manufacturing-led innovation model. We thought we had to lose manufacturing jobs and offshore them because we were high wage, high cost. But somebody forgot to send that memo to Germany. They show that you can be high wage and win manufacturing markets if you innovate in production.

So, it is not enough to develop a scientific idea and publish a paper. We cannot just assume that it is going to go through the stages and get to be manufactured. There is a serious of stages that we have to get right, and we have not paid enough attention to these.

So, let me turn briefly to the bill. I discuss three topics in my written testimony that spell this out in more detail. But concerning tech organization, the bill creates a new tech development directorate at NSF. Will this create a culture clash with NSF? You know, we have, actually, a long history of basic research working alongside use-inspired applied research. The other witnesses today have noted that. The cultures can be complimentary. DARPA works alongside the Office of Naval Research, ARPA-E alongside DOE's labs and its Office of Science. Is NSF the right place to put many of these new elements? It is our one broadly focused R&D agency not tied to specific narrower missions. It does science research in a range of a fields that it is famous for. But our current problem is technology, not simply basic science. We need a new technology development trust, hence this new directorate.

The new technologies need to move through a series of stages. So, for R&D and critical technology areas, the bill supports earlier State's research at existing NSF directorates, and then, later State's research at the new NSF technology directorate. For development and prototyping stages, the next level, the bill support university technology centers. And importantly, these can be consortia, which include industry participants. For tech testing and demonstration, the next stage, the bill supports test beds to prove out and demonstrate the technologies. And then, for scale-up, we are going to need to build regional innovation capacities for scaling up toward production.

Concerning regional innovation—you know, innovation is like real estate, location matters. Innovation has to be scaled up in regions. It does not happen nationally; it happens regionally. So, we need to build our regional innovation capacity. We need regions with committed area firms, with small and—that are both small and large. We need higher education institutions to provide the R&D and the talent. We need backing from State and local governments. And we need strong workforce technical education. And these pieces have to be working in concert. We have to have the regional foundation, so that the U.S. innovation can scale. And a 2019 study suggests that there are some 102 regions, for example, in the U.S. with the potential assets to become regional tech centers, many of which are not that now.

Concerning the workforce, the technical workforce, along with the STEM workforce, are going to have to play a key role in the emergence of these critical technologies. That technical workforce

should be supported along with the STEM workforce, through the tech directorate. It could also work with NSF's existing advanced technical education program, which I know both Senator Cantwell and Senator Wicker have been supportive of. The regions can also play a role in workforce readiness for these critical technologies. So, the workforce element needs to include the technical workforce and it will be vital to scale-up.

This is a moment of opportunity. The Endless Frontier offers an important, indeed historic, opportunity for the U.S. to buildup its innovation system, based on the critical technologies we must have for our national and economic security. Thank you.

[The prepared statement of Mr. Bonvillian follows:]

PREPARED STATEMENT OF WILLIAM B. BONVILLIAN, SENIOR DIRECTOR, SPECIAL PROJECTS, MIT OFFICE OF OPEN LEARNING AND MIT LECTURER

Senators Cantwell, Wicker and Members of the Committee,

Thank you for the opportunity to meet with you today.

I want to emphasize at the outset that this is important legislation that needs to pass. We are facing a challenge to technology leadership that we have not faced before. Our growing trade imbalance in high-tech industries,[1] the fall in our real manufacturing value added output,[2] our declining position in international innovation ranking systems,[3] and the weaknesses in our defense industrial base [4] make it clear that American technological leadership in both innovation and production has eroded.

As this Committee understands, strong competitors are making economic and technology advancements that threaten to displace U.S. leadership.[5] Our current systems are simply not competing well. This requires us to adopt a new advanced technology strategy. Without it the United States will in all likelihood continue to lose market share in a host of advanced industries, including aerospace, life sciences, semiconductors, advanced communications and protocols, and Internet applications, with negative implications for innovation, national security, and, importantly, living standards.

My testimony covers three topics: (1) organizing to meet the tech development challenge, (2) regional innovation, and (3) workforce education. Under each topic, I will make general points about these areas as well as some suggestions for how the legislation can help deal with these three critical areas.

I. Organizing to meet the Tech Development Challenge

The U.S., starting in the post-World War II period, organized its research and development (R&D) around mission agencies, so that the research would serve the mission. The National Institutes of Health became part of Health and Human Services, DARPA and the other defense research organizations became part of the Department of Defense, and the Office of Science served the Department Energy. Over-

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[1] The U.S. ran a trade deficit in advanced technology products of $133 billion in 2019 compared to a trade surplus in these goods of $4.5 billion in 2001. Trade in Goods with Advanced Technology Products, U.S. Census, https://www.census. gov/foreign-trade/balance/c0007.html.

[2] U.S. Share of Global Manufacturing Value Added (controlled for the value of the U.S. dollar) declined from 25 percent in 2005 to 18.4 percent in 2014. Adams Nager, Trade vs. Productivity, What Caused Manufacturing's Decline, ITIF Feb. 2017, ITIF, citing United Nations Statistics, National Accounts Main Aggregates Database (GDP and its breakdown at current prices in U.S. dollars, all countries for all years). U.S. Manufacturing value added as a percentage of GDP declined from nearly 20 percent to 11.2 percent between 1990 and 2021, Statista (based on UN and World Bank data), *https://www.statista.com/chart/20148/manufacturing-value-added-as-percent-of-gdp-in-major-economies/*

[3] See, for example, South Korea Leads World in Innovation as U.S. Exits Top Ten, Bloomberg innovation Index, Bloomberg, 2/2/21, *https://www.bloomberg.com/news/articles/2021–02–03/south-korea-leads-world-in-innovation-u-s-drops-out-of-top-10;*

[4] Office of the Secretary of Defense, Military and Security Developments Involving the People's Republic of China, 2020, Annual Report to Congress, Department of Defense, August 2020, 73, 85, 88, 105, 113, 123, *https://media.defense.gov/2020/Sep/01/2002488689/-1/-1/1/2020-DOD-CHINA-MILITARY-POWER-REPORT-FINAL.PDF.*

[5] Robert D. Atkinson, Time for a New National Innovation System for Security and Prosperity, *Prism* (National Defense University journal), v.9, n.2, March 2021, 60–61, *http://www2.itif.org/2021-PRISM-9-2-new-national-innovation-system.pdf?_ga=2.76279189.1863482471.1617915091-1416244290.1617639922*

all, this decentralized science approach has worked well, and helped us bring science into specific missions. It was a basic research model because the U.S. had been weaker in science at the outset of the war while it completely dominated world manufacturing by the end of the war. So the U.S. didn't have to consider the implementation stages, it needed to strengthen and retain the science base it built during the way.[6] But now we have a series cross-cutting technologies that will serve many missions—AI, quantum, new high performance computing, robotics, biotechnology, cybersecurity, advanced materials, etc. Where do we put a new innovation focus for this range of new technologies?

NSF is our one major, broadly-focused R&D agency not tied to a specific, and narrower, mission. It does basic science research in a range of fields and it is famous for it. But our current problem is technology, not simply basic science—we need a new technology development thrust, and this has not been NSF's job. So, the approach of this legislation is to form a technology-focused sub-unit within the agency—the proposed new Technology Development Directorate at NSF. Some argue this will create a culture clash within NSF. Yet we have a long history of basic and more use-inspired, applied working in tandem and the cultures can be complementary—DARPA works alongside the Office of Naval Research, and ARPA–E alongside the DOE's Labs and Office of Science,.

Creating this tech directorate challenges us to think hard about the follow-on stages to research. To get to new technology as opposed to new science, we need to get through a series of stages, post-research. New technologies must move through: research, development, prototype, testing, demonstration, scale-up/piloting, initial market, full production. The proposed legislation recognizes this. It has inserted institutional elements to match the process:

- *R&D in critical technology areas*—with earlier stage research elements at existing NSF directorates, and later stage research as well as development to be performed at the new Technology Directorate.
- *Development and prototyping*—at University Technology Centers, and importantly, these can be consortia, including industry participants.
- *Testing and demonstration*—new test beds to prove and demonstrate the new technology so they can get into the risk range that industry and other kinds of capital can work with.
- *Scale*-up—could be supported at Commerce Department-designated Regional Innovation Hubs—for scaling-up toward production– preparing the regional tech infrastructure for introduction

U.S. technology history is littered with technologies innovated *here* in the U.S., that did not scale-up here, and were produced *there.*[7] Flat panel displays, solar panels, lithium ion batteries, drones, the list goes on and on. A core goal of this bill is to get the new critical technologies into range of industry acceptance—*here.* The new technologies require de-risking to get into the scope of risk and corresponding costs industry can absorb in implementing them.

Enhancement—Connecting the New Pieces: This bill puts key new pieces on the table, but all these pieces, as the sponsors and the Committee understand, need to be connected. They won't work if they are separate stovepipes. There need to be ties between NSF basic research and the NSF technology directorate. There need to be direct ties from there to the University Technology Centers then to Testbeds for testing and demonstration, then these need to tied to the Regional Hubs to be established through the Commerce Department for scale-up and pilot production.

We need to build a new house of innovation, and we can't do that if the foundation is in one place, the walls in another place, and the roof in a third. So the bill, for example, requires the Tech Directorate to work with (and transfer funding to) existing directorates, and by making clear that the University Technology Centers can be part of the regional hubs.

Innovation economists and technology policy experts have long indicated that innovation must be connected. They tell is that technology-based innovation is the dominant driver of economic growth. They tell us that to innovate, you must have strong R&D, and you must have a strong talent base staffing that R&D system. They also tell us that "innovation organization" is a critical third innovation factor.

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[6] William B. Bonvillian, The New Model Innovation Agencies: An Overview, *Science and Public Policy,* Oxford University Press, vol. 41(4), 2014, 425–426, *https://academic.oup.com/spp/articleabstract/41/4/425/1607552?redirectedFrom=fulltext;* William B. Bonvillian and Peter L. Singer, *Advanced Manufacturing, The New American Innovation Policies* (Cambridge, MA: MIT Press 2018), 34, 37–38.

[7] Bonvillian and Singer, *Advanced Manufacturing,* 57–58.

Innovation needs a series of strong actors, from university research, to gov't research support and labs, to strong companies and supplier systems. You need strong actors and the actors have to connect with each other, so the handoffs are easy and smooth. The new pieces this bill creates will need organizational linkages to each other.

And there is another reason for these close connections: there needs to be two-way street—exchanges so that the tech development influences the R&D not just the R&D influencing the tech development. A linear model doesn't work well—a two-way street is critical so the actors can assist and teach each other. This is another reason why linkages are key between the new pieces. Shared, cross-cutting technology strategies that work linking each of the new institutional elements called for in the bill, shared advisory boards, and Federal agency oversight that emphasizes connections are all part of the solution. There are connections in the bill, but these could be expanded.

Enhancement—Connecting the Other R&D Agencies: NSF is not going to be the only agency doing work on the 11 "key technology focus areas"—we have other mission R&D agencies that are doing important work as well. DOD must continue working on AI and Quantum, for example. We need to find ways to get them contributing together with this new NSF thrust. Agency collaboration is hard in our decentralized science system. And Congress is part of the problem because the appropriations process doesn't cross agencies. We need a mechanism for agency cooperation and sharing. The Office of Science and Technology Policy (OSTP) has its National Science and Technology Coordination (NSTC) mechanism. Better is the mechanism developed for the National Nanotechnology Initiative (NNI).[8] It has a coordination office and, while participating agencies don't share funding with each other, they work on common strategies and attack common R&D problems, cross-fertilizing ideas. We will need such a mechanism here. In addition, we have already created 16 Advanced Manufacturing Institutes, which provide another critical ingredient, and, as discussed below, they need to be further tied in, including into the Regional Innovation Hubs.

Enhancement—Assuring Adequate Resources for R&D at the Technology Directorate: The legislation makes generous percentage allocations to the various program it authorizes—to the University Research Centers, to existing NSF directorates, testbeds, etc. But only a limited amount appears to remain after all those allocations for all the remaining purposes. I believe the new Directorate needs more flexibility than that; a significant percentage should be set to support research awards from Directorate itself. Much of the initial work resulting from the legislation will need to happen through the new Directorate's substantial competitive research portfolio in later stage R&D—these advances will feed all the other follow-on elements in the new system. We will need more breakthroughs to build on, so adequate support here will be a keystone for the system. In addition, I believe the Directorate should use a strong program-manager model aimed at the major technology challenges in the new technology areas, setting milestones for its research portfolios. It has been granted DARPA-like authorities and that is fully appropriate.[9]

II. Regional Innovation

Innovation is like real estate: location matters. Some regions move ahead, some are left behind—why? How can we bring more growth to more areas? The Regional Innovation Hubs in the bill, to be set up through the Commerce Department's EDA and NIST programs, could be a way to encourage regional innovation. How do we make regional innovation work?

We have been studying this for years—Michael Porter's work on innovation clusters dates back over two decades.[10] There has been much regional experimentation—we have many kitchens trying many ingredients and there is no exact recipe. Different regions can make different recipes work. Throwing innovation tasks at struggling regions, however, often does not work. Yet there are examples now of

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[8] National Nanotechnology Initiative, *https://www.nano.gov/about-nni*

[9] The DARPA model is relevant to the proposed Directorate. See, Bonvillian, Windham and VanAtta (eds.), *The DARPA Model for Transformative Technologies* (Cambridge, UK: Open Book Publishing 2020), *https://www.openbookpublishers.com/product/1079.*

[10] See, for example, Michael Porter, Clusters and the New Economics of Competition, *Harvard Business Review,* Nov.–Dec. 1998, *https://hbr.org/1998/11/clusters-and-the-new-economics-of-competition.* For a summary of limitations in the theory, see, for example, Yasuyui Motoyama, What was New About Cluster Theory? *Economic Development Quarterly,* V. 22, n. 4, Nov. 2008, 355–363, *https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.910.884&rep=rep1&type=pdf.*

places that have become hubs of activity. Let me try to summarize a large literature in a few words.

Most believe we need regional ecosystems for innovation to thrive.[11] Typically, such an ecosystem includes an area education and research institution as an anchor for tech research and talent. Ecosystems also seem to need an organized public sector[12] engaged with the private sector—including companies and area business groups—pursuing a joint strategy. Solid larger firms linked to solid supply chains of smaller firms are another ingredient. Regions need to build on their existing regional strengths—not every area is going to be a biotech hub. Workforce education has become an increasingly significant component of a solid regional ecosystem—a number of regions are now encouraging companies and startups to come to or stay in their location because they can offer a trained and skilled workforce tied to employer needs. This mean strong workforce programs for new skills at area community or technical colleges are also a component. Another feature of the legislation is grants to communities to help them build strategies for their regional assets. To summarize a few key points, there needs to a broad engagement in innovation—a big tent—not a narrow single-innovation focus; strong locally-based firms need to be engaged as "anchor tenants;" a connection is needed to the talent pipeline—state university and skills education programs, for example—which will be key to companies; and state and local governments need to be strongly supporting the effort.[13]

Pittsburgh, is an example of a regional success story.[14] It was famously dependent on one industry, and when that steel sector declined, much of the city's well-being was affected. Starting in the 1980s, it was able to leverage existing assets—including strong area universities and state governments that developed on a bipartisan basis a long-term, continuing economic strategy. This combined state and local government, education institutions and heavily-involved business interests, that together advanced high-growth industries and higher-wage jobs. And it included grass-roots citizen involvement. A series of advanced technology centers were formed with area universities, which were at the core of the strategy. So, an advanced technology strategy, building on existing assets, can work for regional innovation. And significant technology advances in areas like computing, robotics and health care followed.

If the Regional Innovation Hubs anticipated in the legislation take on the innovation scale-up role they will need to be located in regional ecosystems that can pull together existing assets like those listed above. To effectively compete for these, they will need to have firms interested in implementing one or a mix of the new technologies and be able to muster their regional actors to show how they can help implement them.

The Regional Hubs (funded through the Commerce Department in the bill) are not the same as the NSF University Tech Centers the bill will create—and that is as it should be. The University Centers will primarily be for R&D through prototyping. More is needed beyond that for successful innovation, and those further steps are outside the NSF role. Additional actors are then needed to move from those research-to-prototyping stages for work on the scale-up of new technologies. Not only universities are needed but regional industry associations, with both small and larger firms and their supply chains, community and technical colleges, and support from area government and economic development organizations. The Hubs are mechanisms to bring this additional combination of actors together. To apply an analogy to the role of the Regional Hubs, once you have the prototype for a new airplane wing, someone has to make sure there's an airplane to put it on and an airline to use it. University Tech Centers can be tied to follw-on Hubs. Are there enough of these Hubs to reach enough areas? While these regional efforts won't work unless adequately funded, the Committee might consider a larger number of Hubs with somewhat less funding for each to stretch regional innovation opportunities further. Not every area will be in a position to compete for these now, so importantly the bill also includes support for regions to develop their own innovation strategies. I saw a similar effort by the Commerce Department to support state manufacturing strategies, as the initial advanced manufacturing institute ideas

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[11] See, for example, R. Atkinson, M. Muro and J. Whiton, The Case for Growth Centers, ITIF and the Brookings Institution, Dec. 2019, *https://www.brookings.edu/wp-content/uploads/2019/12/Full-Report-Growth-Centers_PDF_BrookingsMetro-BassCenter-ITIF.pdf;* Jonathan Gruber and Simon Johnson, Jumpstarting America, How Breakthrough Science can Revive Economic Growth and the American Dream (NY: Public Affairs Publishing 2019).

[12] Ben Armstrong, Brass cities: Innovation policy and local economic transformation, MIT Department of Political Science (thesis), 2019, *https://dspace.mit.edu/handle/1721.1/122404.*

[13] Ben Armstrong Industrial Policy and Local Economic Transformation, *Economic Development Quarterly* (Aug. 2021) (forthcoming).

[14] Armstrong, Brass Cities,143–176

were being considered, and it provided states with a major boost in developing state manufacturing strategies.

Enhancement—The link to manufacturing: The Hubs also have a different role from the Advanced Manufacturing Institutes, which are focused on particular production technologies, while the Hubs will pursue broader technology advances. In particular, the Hubs will need to help bring the new technologies into area companies for actual production. But a key asset they should take advantage of is the 16 existing advanced manufacturing institutes. These Institutes are each focused on one advanced manufacturing area, but regional companies and regional economies will have to adopt a series—they will have to adopt a combination of, for example, 3D printing, digital production, AI, robotics, etc., to optimize production for the new technologies. Many other nations will be after the same advanced technologies listed in this bill—unless we have the most efficient production systems, they won't be made here. The bill calls for coordination between the Regional Hubs and the Institutes, but the Hubs should be required to link to a mix of manufacturing institutes to that can bring their expertise to bear on the groups of advanced production technologies that will be needed for the new tech development areas. The Hubs can be enablers in a broader technology context for the advances the Institutes are nurturing in manufacturing.

The legislation also provides for a significant expansion of the Advanced Manufacturing Institutes, which should be viewed as complementary to the Hubs. These Institutes are both national and regional, the Hubs more regional. The Institutes must develop new production technologies available nationally, and implemented regionally, and the Hubs can help with that regional introduction. The Manufacturing Institutes are organized around particular technology topic areas, and while the bill calls for many more Institutes, there are really not that many different new manufacturing technology topic areas. Yes, we need some more institutes around additional technology topics, but we also need to deepen the efforts around existing manufacturing technologies, to give existing Institutes better ability to better reach not just industry leaders but bring their technologies to small and mid-sized manufacturers and enable new manufacturing skills. The legislation should call not simply for new Institutes, but funding should be broadened for manufacturing technology demonstration and training centers, strengthened small company and workforce programs, and satellite centers for existing institutes in additional locations. The legislation also expands the Manufacturing Extension Partnership program, another important and complementary program, to play a role in the introduction of the new technologies and to work with the Manufacturing Institutes and the new HUBs.

III. Workforce Education

We know that R&D advances require a robust talent development system—so the bill has funding for STEM talent to be educated in the new technology areas. We need this. But one area that needs more emphasis is not only science and engineering researchers but the technical workforce. Technologies will never go into production unless there is a strong technical talent base to implement and produce them.

The U.S. doesn't really have a workforce education *system*—it is missing.[15] Ask an American what high school or college look like and they know, but ask what our workforce education system is and you get a blank stare. Ask many Europeans, and they know—they benefit from systems that closely link work and learning. Our workforce needs to upskill—new IT technologies have entered many sectors, for example –and we don't have an adequate system to train our workers for it. Jobs that require these higher skills are now going begging.

As noted above, some regions are starting to use workforce education as a core economic development strategy. For example, South Carolina is using its state-wide apprenticeship program built around its system of technical colleges to appeal to new and keep existing employers. And now it is developing a new youth apprenticeship program that starts in the junior year of high school—led by the Charleston area.[16] These and efforts in other states reflect a new reality—we have a demographic shift, an aging workforce with a smaller number of new entrant workers. And we have a growing skills gap in the new skills employers increasingly need. When we start to add the new technology this bill envisions, this problem will get worse.

Workforce education is an area where both the NSF and Commerce programs have a role, building on their existing work. In all these programs, the agencies need to work with both business and labor to ensure success.

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[15] William B. Bonvillian and Sanjay E. Sarma, *Workforce Education, A New Roadmap* (Cambridge, MA: MIT Press 2021).

[16] Bonvillian and Sarma, *Workforce Education,* 199–206.

Enhancement—The Regional Technology Hubs can help take on the workforce task: Talent, including technical talent, will be a key element for successful regional innovation. While the bill allows Hubs to have workforce programs, this should be a major Hubs effort, working with area community and technical colleges, with state colleges and secondary schools, to train for the new skills required.

Enhancement—The Apprenticeship Program: The draft of the bill I was provided calls for an apprenticeship program in the new skill areas sponsored by the Commerce Department. One approach would be for these apprenticeships to be tied to the Regional Hubs to help in their skill building in the new technologies.

Enhancement—Can NSF's ATE program help with technician talent in the new technologies? NSF already has a strong Advanced Technical Education (ATE) program; it plays a critical role in updating community college curricula and programs in advanced skills. As noted, the Technology Directorate's education program needs a technical workforce education component in addition to its STEM element—let's take advantage of ATE and include a stronger workforce education element for the technicians and technologists we will need in these new and emerging fields. The bill has a set-aside for community colleges and calls out the ATE program, but the bill could give more guidance on how ATE can contribute, in support of both the new Directorate and the Hub programs.

Summary

Overall, as I said in my opening comment, this is important legislation that will play a key role in renewing our innovation leadership. It speaks directly to our national and economic security in ways no other recent legislation has. The U.S. innovation system is at a crossroads, and this bill presents an opportunity to take a strong new path.

Concerning the *organizational elements* in the bill, the pieces are there that can take us through the stages of innovation—

- *R&D in critical technology areas* at existing NSF directorates and the new Technology Directorate.
- *Development and prototyping*—at University Technology Centers, which can be consortia, including industry participants, and in the tech transfer program.
- *Testing and demonstration*—with new test beds.
- *Scale*-up—assisted by the Regional Innovation. Hubs

We also need to make sure the new pieces form a system, that there are links to other R&D agencies working in these areas, and ensure the right resources and organization for the new Technology Directorate.

Concerning *regional innovation,* since innovation has to be implemented and scaled-up in regions, the Regional Hubs can play this role. They, in turn, can link to the Advanced Manufacturing Institutes which can assist them with the new production systems and processes to turn critical technologies into products.

Concerning *the workforce,* the technical workforce along with the STEM workforce will play a key role in the emergence of the critical technologies. That technical workforce can be supported through the Technology Directorate, working with NSF's existing ATE program. The Regional Hubs can also play a key role in regions on workforce readiness for the critical technologies—the workforce will be vital to scale-up. And the apprenticeships can be linked to the Hubs as well.

The Endless Frontier Act offers a very important, indeed historic, opportunity for the U.S. to build up its innovation system based on the critical technologies we must have for our national and economic security.

Chair CANTWELL. Thank you so much, Mr. Bonvillian. Thank you for your testimony today. I am going to defer my round to a colleague who needs to get somewhere urgently, Senator Tester. Thank you so much.

STATEMENT OF HON. JON TESTER, U.S. SENATOR FROM MONTANA

Senator TESTER. Thank you, Madam Chair, and thank you, Ranking Member for having this hearing. It is really important. I want to thank Senator Young for the work he has done on this bill.

Mr. Bonvillian, you're on the clock right now. You talked about structure, you talked about workforce, and I think how we spend

the money is critically important, if we are going to get maximum bang for the buck. But let us just give you a few numbers that you already know, by the way. The Endless Frontier Act provides $100 billion investment in basic research. NSF receives $8.5 billion for FY21. The Chinese government is approved to spend $1.4 trillion over the next five to 6 years on new communications tech and infrastructure, to accelerate China's progress in smart manufacturing. They also—China also plans to spend $150 billion in reducing its microelectronic dependence on foreign firms. The U.S. invests about 1 percent of GDP into Federal R&D. China invests 2.15 and has plans to invest 2.5 percent.

Do you think the amount we are spending on R&D right now, Mr. Bonvillian, is adequate, or are we behind the curve from the beginning? And if somebody else wants to respond to it, after Mr. Bonvillian, you can. Mr. Bonvillian.

Mr. BONVILLIAN. You pointed out the disparity between—you know, the levels of R&D spending that we are making now are still the same percentage of GDP that we have maintained for an extended period of time. So, we are going to need to increase those levels of investment. But equally important is not only to undertake the right levels of investment, but we have got to make sure that we have got the system to take great advantage. Put the different stages into place here. And that is one of the reasons why I appreciate this legislation. It attempts—it is an attempt to build in the stages that we are going to need, to make these investments, to start to scale up.

But we cannot afford to lose leadership in these critical technologies. You know, our economic security and our national security are really going to be dependent on this list. And those are not different problems. Our economic security and our national security are now deeply interrelated.

So, Senator Tester, I concur that we have got an issue with the investment levels that we are making in R&D. We are going to need to expand those, and we are going to need a focus on the critical areas that we have got to have.

Senator TESTER. So—and this goes to anybody who wants to respond to this. I just got off the phone with Southwest Airlines today and they are very concerned about climate change, as we all are. And they were talking about the lack of biofuels. And I think we have learned that it is not probably going to be smart to put food into biofuels. But there are other opportunities out there. We have got a forest in Montana that has been attacked by beetles. The trees are virtually laying on the ground. So, there is stock.

And then, I went to another plant last week where they are building products for our fighter jets that needs germanium. And by the way, the only place we get it, as you guys know, is Russia and China. It does not seem to be very smart, from a national security standpoint.

Could you guys touch on, number one, how we address—how we prioritize to address some of the issues that I think are really important, like climate change and national defense in an R&D structure with this Endless Frontier Act? Anybody want to speak to it?

Chair CANTWELL. I think Dr. Miranda——

Dr. MIRANDA. Senator Tester, on your first question, if we are investing enough, I—oh, sorry. On your first question on whether we are investing enough, I would—I would just like to give the simple answer, no and I think the Endless Frontier Act is incredibly important for us to do that.

I am from the University of Notre Dame, so we like to use football analogies there. So, the way that I would describe it is, we have a world class football program. Our R&D program in the United States, it is world class. There is no doubt about it. It is the envy—the way that we built up our research and development, in the post-World War II period, is the envy of the rest of the world, and many people—many other countries were copying it. But even as we have a world class football program, every team in the league has gotten better. And so, the competition on the field is much more fierce. It is much more intense. And therefore, this kind of, doubling down on investment and thinking about our level of R&D investment, relative to the percent of GDP, I think is an excellent way to think about it.

Senator TESTER. OK. What about investment and things with the deal with climate change and national security? How do we direct those and does this Act help in that direction?

Dr. MIRANDA. So, if I were up to me, of the 10 focus areas named in the Endless Frontier Act, climate change would be one of them.

Senator TESTER. OK. All right. Sounds good. I just want to thank you all for testifying. This is a committee meeting where we could ask questions for 30 minutes and not even come close to the number we have. I want to thank the Chairman for your courtesy.

Chair CANTWELL. Well, thank you, Senator Tester. You know, we might go a second round, who knows here. But clearly the subject matter deserves a lot more attention and getting this right is important, I think, as everybody has pointed out. Senator Wicker.

Senator WICKER. Thank you very much. Very good testimony from everyone of you. Dr. Butler, is there a valley of death between conducting research and actually developing commercially viable products? What went right with Camgian and what deficiencies do you see in the proposed legislative concept, or in what we are doing now?

Dr. BUTLER. Very good question and thank you for asking. I think there is a model to be had where there is tight coupling between the high-tech entrepreneurs in the country and the universities. And we have actually executed this model at Camgian, and I will speak to some of the benefits of it.

But just speaking on behalf of an entrepreneur, the only thing that matters to us is what I would call product market fit. Nothing else matters in our business. And that is building a product that will gain adoption in the marketplace in scale. So, that is all we do every day. That is our focus. And as we think about opportunities in the market, we are constantly looking for those underserved needs. We are constantly trying to understand how we build a product to address those underserved needs, and then, how we scale those products accordingly.

Universities think very differently. Universities think about innovating, or inventing, new technologies that can have groundbreaking impact on society. And I think when you couple

those two together, you have a very good model for getting these technologies to market.

So, a couple of points, to your point of crossing the valley of death. So, there is one model where a company like Camgian can engage with the university and look at new inventions, new research that is coming out of the university, and work with them on identifying those underserved market needs and putting a plan in place to get a product to market.

There is a second model that we have also been very successful with, and that is the model of us teaming with the university, to go after a new product, or a new capability in the market. And we have done this at Camgian with Mississippi State University, where we have acquired applied research funding from the DOD, and the DOD has asked us to build a new capability. And we put a product development plan, or a capability development plan in place to do that, but then, we look to our university partners and say, here is a component of this plan that is the high risk, high payoff piece of this. And if you can accomplish that goal of delivering that, as part of a research program, we can then incorporate it in the system that we ultimately deliver to our war fighter. And we have actually done that successfully in a partnership with Mississippi State.

So, I think there are two models, but I would—I would advocate that, as part of this bill, we find ways of bringing the entrepreneurs together with the universities, because we have very different skill sets. But I think the skill sets are tremendously complimentary and it will result in an increase in the success of moving research to innovation to product to market. Because again, if we do not do that as entrepreneurs, we do not survive. So, it is really the drive, determination, everything that goes along with getting a product to market that we would bring to the table, in such a relationship.

Senator WICKER. Thank you much. Dr. Shaw, of course, we read your prepared testimony. Nearly half of Federal research dollars, over the last 20 years, went to just six states, with more than one-third just to two states, California and Maryland. And I love our friends in those states, but we are going to need expertise, talent, and capabilities of all Americans. What specific steps should we take—and let me just say, Madam Chair, I am really not interested in advancing a bill that does not address this disparity. I think Indiana and the State of Washington, and even Minnesota, are not getting their fair share.

So, Dr. Shaw I have taken part of your time to answer this, but perhaps the chair will indulge me.

Dr. SHAW. Thank you, Senator Wicker, for the question. And as I mentioned, both in my oral and my written testimony, this is a vital question that needs to be dealt with as we consider the changes that are being proposed.

As I mentioned, the opportunities that we have in Mississippi, just like in all of the other parts of this Nation, to be able to address the challenges, but also the opportunities, are vital for our future. From our standpoint, at Mississippi State University, we have taken full advantage of the opportunities that have been created in programs, such as the EPSCoR program, with the National

Science Foundation. And frankly, I applaud Congress and the Foundation for the creation and the expansion of that program. So, I think that is one vital aspect of the proposed legislation, is to be able to continue to look at how to be able to expand that program so that institutions, in all of the jurisdictions in the United States, have the opportunity.

I think above and beyond that, there needs to be serious consideration about being able to provide a portion of the funding that is being considered for institutions that fall outside of the jurisdictions that, historically, have seen that. I think there is certainly the opportunity to be able to think about, beyond the EPSCoR program, ways that this legislation could be crafted, such that, we have an adherence to a high degree of competitiveness. Rather, it is in no way looking to be able to just dissect the program and provide it on a per capita basis, but rather fund competitive research. But at the same time, ensure, through legislation, that we have the opportunity to see institutions, like Mississippi State University, like the University of Notre Dame, like so many other institutions that have a tremendous pool of talent. Not only in our faculty, but especially in our students as the workforce of the future, to be able to have the opportunity to be exposed to the research opportunities in our laboratories and with our researchers, and to be able to, ultimately, create the economic development that we want to see across the entire United States.

Senator WICKER. Thank you, sir, and I thank the Chair for indulging me on allowing me to make a little speech there. I yield.

Chair CANTWELL. Thank you. Well, I just want to assure you, I definitely think the Information Age economy should take place everywhere. And that is what is the secret of it, is that development and information can flow lots of places, and so should the R&D. Senator Klobuchar.

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

Senator KLOBUCHAR. I thank you very much, Chair Cantwell. Thank you, Senator Wicker, and thanks to everyone that is working on all of this Endless Frontier of issues. So, I am very focused on manufacturing. My state is the state that brought the world everything from the pacemaker to the Post-it note. And one of the proposals that I have, actually in a bill introduced with Senator Wicker, along with Senator Coons and Portman, focuses with the companion—bipartisan companion in the House with Marcy Kaptur, focuses on an Office of Manufacturing and Industrial and Innovation Policy, in the Executive Office of the President, to help strengthen America's manufacturing industry.

And I guess I would turn to you, Mr. Bonvillian. In your testimony, you highlighted the importance of agency collaboration for technological innovation. Can you speak to the importance of Federal coordination between agencies in developing measures to solidify U.S. leadership in scientific and technological advancement?

Mr. BONVILLIAN. [Transmission broken] I share your interest and concern in getting a strong focus on manufacturing into the White House, to coordinate the activities that are going on with different agencies. You know, in general, we describe innovation as a team

sport and it truly is. And there are some issues that we need to address in this legislation to be sure that the bill tackles this, in terms of coordination between agencies.

You know, one issue is that we need to look into is that the coordination mechanisms set out between what this new NSF directorate is going to be undertaking, in a serious of advanced technologies, is happening with the other agencies that are already working on these territories, right? Obviously, DOD is doing a tremendous amount of work on the AI. They are doing tremendous work on Quantum.

Senator KLOBUCHAR. Exactly.

Mr. BONVILLIAN. We need to coordinate these pieces. And look, the U.S. system, it is a very decentralized system for science and tech development, right? And frankly, that is, historically, going to strengthen. But there are times when you need to pull the pieces together and get them to act in coordination with each other. We have a hard time doing that with our decentralized agency system.

Senator KLOBUCHAR. OK.

Mr. BONVILLIAN. One mechanism, when we worked on nanotechnology, was to create an office around that topic, that the different participating agencies could join into and develop common strategies and share ideas across and make sure that they were understanding each other's advances and developments. I think that kind of mechanism might be very useful in this bill, in these different technology areas, to assure Federal agencies are pulling together and that what has been going on—what will go on if the new directorate will enhance what is going on some of the other locations?

Senator KLOBUCHAR. OK.

Mr. BONVILLIAN. We also need——

Senator KLOBUCHAR. Thank you. I am going to—you know what I am going to do? I am going to—because I have such limited time, I want to ask a few other questions. Do you want to just say your second point in a few seconds here?

Mr. BONVILLIAN. Linking to the advanced manufacturing institutes is another important piece.

Senator KLOBUCHAR. OK. That is exactly right. Thank you very much.

Dr. Shaw, workforce training, as I look at, what we call in—I was just in Duluth. The Mayor of Duluth said, the lighthouse on the horizon, as opposed to light at the end of the tunnel with the ending of this pandemic. So much of this is going to be about, again—somewhat because of the pandemic, but what we had before the pandemic. Making sure we have people trained to do the jobs of tomorrow. As I often said on the campaign I ran, about a year or two ago, that we are not going to have a shortage of Sports Marketing degrees in this country. We are going to have a shortage of plumbers, electricians, construction workers. Could you talk about making sure we are training people for the various skill levels of the jobs that we need, and how we get there?

Dr. SHAW. Thank you for the question. And it is spot on with things that we need to be considering, as a part of the legislation that is being considered. You know, Mississippi State University, for example, works very closely with the community colleges in the

State—throughout the State of Mississippi, to be sure that we are addressing all of the needs in the state, and not just in a particular area, or a particular discipline. And the opportunity that we see, for example, with the program that we just created this last year, through what is called a Bachelor of Applied Sciences, to be able to allow students to go down a technical track, at a community college. But then, to be able to have a new degree program that they can now move into as they are participating in the workforce, but now they are looking for a bachelor's degree, to be able to advance to become a supervisor.

Senator KLOBUCHAR. Mm-hmm.

Dr. SHAW. To get a promotion. Now they have that track at Mississippi State.

Senator KLOBUCHAR. Very good.

Dr. SHAW. And this is—this is a model, by which we see the opportunity, through that very close partnership, to be able to address all skill sets, rather than a particular segment.

Senator KLOBUCHAR. And I know I am out of time, and I will ask this in writing, but I know, Dr. Miranda, you would agree. Part of this is also advancing women, people of color, in getting into this market for the skills that we need, and there are a lot of different ways we can do that. And I appreciate everyone's work on that.

Chair CANTWELL. Thank you.

Senator KLOBUCHAR. Thank you.

Chair CANTWELL. Senator Thune.

STATEMENT OF HON. JOHN THUNE,
U.S. SENATOR FROM SOUTH DAKOTA

Senator THUNE. Thank you, Chair Cantwell, and thank you to all the witnesses for being here today as this committee considers the Endless Frontier Act. Especially with the rise in scientific prowess of China and other nations, it is imperative that the United States maintain its global leadership, in the development, commercialization, and standardization of innovative technologies.

During my time as Chairman of this Committee, we successfully enacted the American Innovation and Competitiveness Act, to better coordinate R&D efforts at the Department of Commerce and the NSF, as well as the National Quantum Initiative Act, to strengthen and unify the focus of the Federal Government on developing Quantum technologies. Both of these bills were bipartisan and drew broad support from industry and the scientific community.

As a move to consider any potential opportunities the Endless Frontier Act presents to further enhance U.S. technological leadership, let me start by saying that I would have appreciated the chance to review an updated version of the legislation before this hearing. As I understand it makes substantial changes from the version introduced last Congress. And legislation, obviously, of this scope and importance, with such profound implications for the Federal research enterprise, needs thorough review by this committee.

I also want to make a few additional points, quickly, before I move to questions. First, NSF certainly plays a key role in fundamental research. But there are several other government agencies with substantial experience in technology development and applied research. With such a substantial authorization of funding in the

Endless Frontier Act, greater incorporation of other science focused agencies merit strong consideration and would even more substantially contribute to U.S. technological leadership.

Second, I believe that the private sector plays a critical role in the pipeline from fundamental research to commercialization. My home state of South Dakota, our universities have successfully patented technologies that started with basic research and the State's economy has benefited, as a result. Any solutions that strengthen that partnership will greatly improve this bill's effectiveness.

And finally, it is crucial that states like South Dakota are not left behind by this bill. Much of Federal research funding is concentrated in a just a few states, and this bill should seek to change that model. So, I want to thank you again for holding this hearing, Madam Chair, and appreciate the witnesses being here, panelists in providing their expertise.

Dr. Droegemeier, you mentioned in your testimony, the directives to USF made by this legislation should not duplicate activities undertaken by other Federal agencies. And given the substantial investments already made in research infrastructure at other agencies like DOE, I share this view. Could you elaborate on how a framework like that contemplated under the Endless Frontier Act could be modified to better recognize and incorporate the role of other Federal research efforts?

Dr. DROEGEMEIER. Senator Thune, thank you so much for the question and for the excellent work that you have done, as you just described, with the Quantum and many other areas.

You know, we have been talking about all the important activities associated with the bill and we have mentioned the importance of working together, but we really need to talk about the how of that. As you say, Department of Energy laboratories have extraordinary capabilities. South Dakota itself benefits from a lot of that kind of work. We have other laboratories, Federal and national laboratories both. We have private sector facilities. The question is, how do we bring all of them together in a way to where, each time we do it it is not a new one off all the time? You know, Mississippi State working with a small startup company, that takes a lot of work to get that thing going, and we cannot just keep doing the one offs all the time.

So, what we really need is a broader framework. And one was, in fact, recommended by the President's Council of Advisors in Science Technology, issued, in fact, just a few months ago. Talking about a framework that would bring all of these activities together in ways far different than what we have done in the past, with the exception, perhaps, of Bell Laboratories, which was really a unique model that does not really exist today in the way that it used to.

And really, the whole point is to go from fundamental curiosity driven research, all the way to product scale up, and pre-production prototype development, all within the same framework. We suffer from what I, kind of, call the "hand off and hope model." There are many points of hand off in this process, but we do not really have the capability to do a seamless front to back system, you know, all the way across. So, that really leverages all of the facilities that you are talking about.

So, I think the bill, if we could think about it in the context of that language in the bill, of taking these pieces and bringing them together. As our friend from MIT mentioned, sometimes we have to bring things together, not in a necessarily formally structured way, but in a way that allows us to have people move across organizational boundaries. To have intellectual property negotiations done right up front, to where we can really accelerate the innovation. This is what China does, but we do not want to do it like China does. We want to leverage the capabilities of our enterprise in a way far different, more ethical, and more appropriately so. And I think we could really do a lot to compete in that way.

So, the pieces are there, but I think the question is how do we bring them together and that, I think, is something we ought to contemplate for the bill.

Senator THUNE. OK, very quickly, Dr. Shaw, you had noted, and I—this has been asked, I think, already, but in the latest version of the bill, there are more considerations to—meant to improve rural areas. But what would you recommend to ensure that universities in states like South Dakota and Mississippi are not left out?

Dr. SHAW. Well, thank you. I think the—as you indicate, the opportunities need to be across the entire spectrum. Zip code does not need to be determining how we are successful. I think there are several different direction that could possibly be taken. You know, South Dakota, as Mississippi, is a portion—is a member of the EPSCoR program. And I think that is a vital program and I think seeing it expand is a very important aspect of that.

I think the second part of it, though, really—which may be even more important, is the recognition that there are pockets of excellence at institutions across the entire nation. Institutions in South Dakota, as well as institutions like min, have excellent programs in—for example, in our program, such as the high-performance computing aspects of what we have. We are a leader in unmanned aircraft systems. So, there are a number of those types of programs. And I think the National Science Foundation, through the legislation that is being considered, should be able to more adequately and appropriately recognize those pockets of expertise and allow them to be able to expand. So that we have tremendous opportunities that get created across the entire United States.

Senator THUNE. Thank you. Thank you, Madam Chair.

Chair CANTWELL. Thank you. I am going to ask questions now because I want to follow on what Senator Thune and some of the other questioners have been asking, which is really to get to crux of this issue of, how do we grow ecosystems where they are not as robust? And how do we take advantage of ecosystems that are already pretty robust and continue to grow them, as well?

And so, my question I think, to Linden Rhoads, is, you know, when you did five or six things at the University of Washington, which was basically to bring the entrepreneur ecosystem into the university, is really what you did and help fund it, whether that was writing patents or helping with various ways. How applicable is that model to other institutions across the United States, and should we be giving some of the R&D money to that, building capacity at universities?

To the rest of the witnesses, to what degree, Dr. Shaw or Dr. Miranda, or Dr. Droegemeier, to what degree does the Rose-Hulman model work, where you are basically a fee-for-service model—you have a regional hub where everybody is going to that hub and basically saying, solve my next generation technology problem. And in that case, there is not a big, you know, NSF dollar amount. I mean, there is some but, you know, people teach there because they want to teach. People do not teach there because they are going to publish their next NSF research. And yet, they have become a hub for solving a lot of regional, very great innovation programs. Or to what degree does Dr. Butler's point about having a DARPA model work, where basically you are giving contracts to companies to help solve that problem?

So, I do not know which one of you now in the testimony, basically said, start at a higher level. Get the companies and the sectors communicating at the higher level of NSF funding, and DOE funding, for that matter. And then, keep the relationship going throughout the system.

So, my question is, there are three different things that we already know, right now, that are working. The DARPA model is working. A fee-for-service model and helping big research institutions do more R&D by bringing the entrepreneurship is working.

So, Linden, I am going to start with you. How much do you think the University of Washington model could be translated to other institutions?

Ms. RHOADS. Well, I think it is a very perspicacious question because, unfortunately, there is not a cookie cutter model that fits for every region or university, depending on its starting point and its issues and gates. And by way of example, when I started at UW, several experts told—mostly in computer science, told me, this is simple. Fly down to Stanford, meet with their head of tech transfer, just do exactly what they do. But Stanford was located a mile from the largest constellation of venture capitalists in the history of the world. And their challenges are different from our challenges, at the University of Washington, where we are in the remote, northwest corner of the continent, and a flight away for most investors. And even though we have many vital industries, we do not have anywhere near the kind of nexus between industry and investors, and our researchers could not have been more different. And we needed much more heavy lifting, therefore, for our researchers.

So, what was working for this one, you know, very accomplished university, in terms of translation, would not have been sufficient for us. And so, I think—I do not know that there is an easy answer, but I do not think that everything that works in one place works elsewhere. And I do think, unfortunately, that you need this full panoply of services to synergistically interact between funding and mentorship and IP support, to really get the results we are looking for. And so, in some cases, one university may be able to, with substantial—adequate funding, provide those for itself and in other cases, you may need regional collaboration and support.

And last, I would just like to say, apropos of one of the things you just mentioned, I think the I-Corps program—the I-Corps hubs program the NSF has launched, my colleagues in tech transfer

really laud those programs in that they train researchers to pursue customer-directed discovery and focus on the end user. And I think that any programs that do that are very helpful to what we are all looking to see happen.

Chair CANTWELL. Quickly.

Dr. SHAW. I would certainly, whole-heartedly agree with everything——

Chair CANTWELL. Linden just said.

Dr. SHAW. That our previous witness just said. The three things that I would touch on quickly, in addition to that is, I think the call for closer coordination with other agencies. You know, for example, the Department of Commerce funds our Calves Extension Center, to be able to work with manufacturing entities to do problem solving and to be able to grow manufacturing capacity in our State. I think it is a really important aspect that needs to be covered as we consider this.

You know, I think the very fact that Camgian Microsystems is located in our Thad Cochran Research and Technology Park, the creation of that ecosystem in which developing businesses can have the opportunity to work closely in partnership with our faculty is incredibly important.

And then, finally, the Entrepreneurship Center that we have located on our campus that really is focused on student entrepreneurship and the opportunity to bring business students and engineering students, to be able to create new businesses, is incredibly exciting and needs to be recognized as a part of this effort.

Chair CANTWELL. Dr. Droegemeier, anything to add?

Dr. DROEGEMEIER. No, thank you.

Chair CANTWELL. OK. Anybody else? OK, I think Senator Fischer is next.

STATEMENT OF HON. DEB FISCHER,
U.S. SENATOR FROM NEBRASKA

Senator FISCHER. Thank you, Senator Cantwell. While we do not have any legislative text in front of us at this moment, I do appreciate the witnesses here today who have spoken to core issues of how lawmakers can both strengthen and preserve the integrity of our Federal scientific research.

Dr. Droegemeier, in your testimony you compared the Endless Frontier Act focus on use inspired research and technology domains with the fundamental, or curiosity based, research that the National Science Foundation is based on. Given a proposal that would dedicate significant funding to NSF in the context of a new technology directorate, how do you believe that this could affect NSF's mission, positively or negatively, to support fundamental research?

Dr. DROEGEMEIER. Thank you, Senator, it is a great question. I think it could be very complimentary, in fact. As I mentioned earlier, NSF actually already does fund quite a bit of use inspired research, even in my own field in meteorology. Some of the work that we do in trying to develop more effective radars and things like that, is very much inspired by more accurate forecasts and so on, and so forth. So, it is not a foreign concept to NSF.

So, I think that the notion of curiosity driven research and, sort of, use inspired research, they can be very much mutually rein-

forcing. So, I think a new technology directorate could—could really do a couple of things. One, it could, kind of, weave together and provide connective tissue from fundamental research and the other directorates into the technology domains that are mentioned in the bill.

But more importantly, I think the technology directorate could then build the connective tissue linkages with the private sector, at the institutional level, as Chair mentioned just a moment ago, to where, in fact, you do not just have individual faculty and individual awards taking a lot of time to try to build bridges and build relationships with private sector. But you actually have the head of a major foundation that has been around for 70 plus years, working with the head of other companies to build those strategic partnerships. So that when—when we actually go out and start to do translation—transition from basic research to applied to so on and so forth, though the valley of death to product and service at scale, it is a seamless framework. The thing has already been put in place.

And so, I think, in that sense, we are reinforcing fundamental discovery type of research at NSF by creating a technology directorate. And I know there are some who fear that technology could overtake, you know, the fundamental research. But I think we can do this in a careful, thoughtful way to where, in fact, they are much more mutually reinforcing.

As we have heard before, from our friend from—from Notre Dame here, the fact that, you know, her work depended upon basic research, but she worked in the applied domain. But it is not a single pathway. It is a reentrant, multiple of circuitous pathways. So, I think this could, in fact, work quite well. And I really believe that a tech directorate at NSF could really strengthen the foundation overall. But we certainly want to make sure that NSF does not lose its fundamental underpinnings of discovery research as being its true—true foundation.

Senator FISCHER. OK. You know, as we look at America's competitiveness, and the scope of our technology readiness to determine where we invest Federal dollars, there are of course a variety of agencies and programs with key roles, here in the Commerce Department, and beyond that. Dr. Droegemeier, I know you referenced this with Senator Thune, but would you agree with this sentiment?

Dr. DROEGEMEIER. With—Senator, I am sorry, of what, specifically?

Senator FISCHER. You know, as lawmakers seek to advance America's competitiveness in emerging technologies, especially when we consider the foreign threats, do you think agencies besides Commerce Department—outside of Commerce Department, like DOD or DOE, the national labs, should they also be a part of this conversation?

Dr. DROEGEMEIER. They absolutely have a great deal to offer, Senator. I think, to me—you know, in my written testimony and also I mentioned orally that NSF has really been overlooked for a long time. And what is unique about it is it funds, you know, many, many domains of science outside of medical, clinical research and it is, in fact, the largest funder. So, it is really critically important

that, in and of itself, NSF get a very substantial increase in funding. But yet, on the other hand, it is not a zero-sum game. So, I think collaborating with, say, DOE national labs and Federal laboratories and other agencies like NIST, and so on, very, very important.

And that ecosystem is really what makes America so powerful and when we talk about the China threat, they do not operate that way. And frankly, I am a huge fan of the DOE's 17 national labs and I think that, in some sense, they are our X factor, and they can play a terrific role, as they are already doing, in so many of these domains and Quantum and artificial intelligence in advanced manufacturing, as well.

Senator FISCHER. Yes. Thank you, sir. Thank you, Chairman.

Chair CANTWELL. Thank you. Next is Senator Schatz.

STATEMENT OF HON. BRIAN SCHATZ,
U.S. SENATOR FROM HAWAII

Senator SCHATZ. Thank you, Chair Cantwell. Thank you to the Ranking Member. Thank you for this really interesting panel.

You know, newly minted PhDs and post-docs drive science and technology innovation and, consequently, the economy itself. And yet, I understand we lose many of them because of how hard it is to get a faculty or research position after graduate school. And so, my first question is for Dr. Miranda. We recognize the importance of emerging researchers. Can you speak to the importance of emerging researchers, and specifically, we are considering legislation to establish a grant program to help these emerging researchers to continue their research and to publish? In other words, to kind of open up an alternative pathway for some of these newly minted PhDs and post-docs.

Dr. MIRANDA. Thank you for the question, Senator. So, first of all, I would say that there are a whole series of mechanisms that the NSF and other federally funding agencies could implement. One, we have the National Science Foundation Graduate Research Fellowships, if you thought about some equivalent kind of program that operates at the post-doctoral level. So, there is—we talk about the valley of death and commercialization. There is a valley that researchers travel, as well, where they move from being a graduate student to establishing an independent research career. So, a GRF-like program at the post-doctoral level, I think, would be incredibly effective at helping with this problem.

The second thing I would say, there is a very nice program that exists within the National Institutes of Health, which is the Early Investigators which addresses all sorts of problems, all these K awards. In the National Science Foundation, we have career awards. I would tell you that there are many more—I think all of us who have been spending time at universities, will tell you that there are many more people who are deserving of an NSF career award than the NSF is able to offer. So, beefing up and adding funding to the NSF career program, which is already a proven program would be incredibly helpful since we already know that the ROI on it is good.

The other thing that I would say is that, speaking to some of these points about the collaboration between universities and in-

dustry, it is actually pretty common in science and engineering that we—we have lots of our students who go on and become professors. And we always like it when our kids grow up to be like us, right? But we are actually really happy when our students—when our science and engineering students go on to work at companies. And I think that we have to do a better job, in the academy, and we are starting to do that.

And I could imagine a whole network system that NSF could set up, to help teach students about how to be prepared to be effective in industry. And I think about some public university—some company or industry-university partnerships, where our graduate students go and do a—one of their research rotations. Not just doing research rotations around labs around the university, but doing research rotations at industry locations, so that we get a better sense of how does industry work? How does academia work? And I actually think that it would really help—that type of a program would really help build the kind of partnerships that my colleagues from Mississippi were talking about, where the university is deeply tied to a whole series of regional corporate partners.

Senator SCHATZ. Thank you. This is—these are really good insights and look forward to working with you and all the panelists on developing, at least, our portion of this legislation. You know, recent reports show that, in spite of decades of efforts to increase diversity, the workforce remains largely homogenous. And I think that is partly because you do not have these, sort of, institutional networks available for people who are new to these fields. But also, because the requirement, if you are going to, sort of, climb the ladder, is to work for so little that not everybody can swing that. Not everybody can carry a debt load and get paid very, very little.

And so, it works like a reverse sieve, where people who are already plugged into institutional networks, where people whose parents can subsidize their post-doctoral research, are able to, kind of, hang in there all the way until they climb the ladder. And I am wondering if you might speak to the need for institutional support, and whether you think that is a real issue, in terms of where someone comes from economically, actually impeding their progress up the research ladder and into a profession where they can land doing where they—land doing what they want to do.

Dr. MIRANDA. I think that was for me.

Senator SCHATZ. Yes, Dr. Miranda.

Dr. MIRANDA. So, first of all, for those of us who live in flyover territory, we are a little bit tired of being referred to as flyover territory. There are an enormous number of incredibly talented people from across the geography of the United States and from across the income span of the United States and from across the great racial and ethnic diversity we have in our country.

I do think that we need to ensure that we have a large enough, and diverse enough, workforce—both of those are important. And I define diversity across many metrics. For us to have a large enough and a diverse enough workforce, and to keep people in the program, these kinds of things, like the GRF, which definitely help—I had an NSF GRF. I never had to take out a loan when I was in graduate school. Having similar programs at the post-doc-

toral level, having more of these Early Investigator awards, makes a huge difference.

It is also the case that while, I do agree that money does not buy happiness, but it does buy lab equipment and travel to conferences, and those sorts of things. But the other thing that these—that we need to ensure the true, full diversity, is a series of networks that are built across—you know, so, we have all kinds of programs. We have all kinds of organizations like the Association of Women in Mathematics, the Association of Women in Science, the Black Physicist Organization, the National—NSBE, the National Society of Black Engineers. We have a whole series of these organizations, which are meant to provide networks and advice and guidance and mentoring and support——

Senator SCHATZ. Thank you, I am a bit over time.

Dr. MIRANDA. Oh, sorry.

Senator SCHATZ. No, that was great. I just want to respect the other members. Thank you very much. Look forward to working with all of you.

Chair CANTWELL. Yes, we will let people elaborate on this in their written answers, too. So, Senator Young.

Senator YOUNG. Thank you, Madam Chair. Again, thank you so much for holding this hearing. Thank you to my colleagues for their probing questions. I see a lot of commonality, as I am listening to my colleagues and the answers that are provided. We just need to find ways to get the pieces to fit together in a more comprehensive fashion.

So, we introduced the Endless Frontier Act last year and we are improving significantly on it, with your counsel and that of others around the country. So, in coming weeks, I think we will have a product that we can all rally around, which will be really important because this is not just about innovation, sort of in vacuum. This is about advancing the common good. And it is about our competitiveness, vis a vis, the Communist Party of China.

We have done this successfully in the past as a country, as we think about the Cold War and the examples to be learned from there. In the 20th century, the United States led the world with investments in science and technology and infrastructure, that would highlight the crucial role of the Federal Government in catalyzing innovation in national defense and economic security and American prosperity. The Apollo program may be one of the greatest examples. In response to Sputnik, the Federal Government spent, in today's dollars, $140 billion to land a man on the moon and to win the space race. The success of NASA would lead to spinoffs in hundreds of new industries. New products came online. And American leadership in aerospace was realized. By 2018, U.S. dominance in aerospace alone contributed $2.3 trillion—that is 1 year—in GDP to the U.S. economy. The seeds were planted back through Federal investments. That is not an unusual model. This is not a distorted reading of economic history.

I believe we are starting another Sputnik moment right here. Only this time it will be with China's investments in research into emerging technologies taking place along side this. We have a different model. We should harness our unique talents and ensure

that we are harnessing the talents of people across every state and across our various universities and labs and so forth.

So, as we introduced this bill, which we are aiming on proposing $100 billion in investment in R&D over a 5-year period, in 10 key emerging technology areas, perhaps others will be added, we recognize and embrace the global challenge that China presents. These funds would be used to crowd in—I want to emphasize this—the expertise of private industry, but also, of our global partners and allies. So, as China looks to develop an illiberal sphere of autocratic, authoritarian regimes, we need to cement our relationships with partners and allies, their expertise, their ideas, their private capital. The Trump Administration estimated we could get $5 crowded in for every single taxpayer dollar. Let us say they were way off. Let us say it is $2. That is a pretty strong lever of investment.

Dr. Droegemeier, what are the risks to the United States if we are not successful in this competition over technology and innovation with China? In short order, what happens if we get this wrong and fail to act?

Dr. DROEGEMEIER. Well, thank you, Senator Young, for your tremendous work on the bill. I think we lose out in many ways. We lose out on economic security. We lose out on national security. We lose out on our ability to innovate and really stay strong in the world. We are a beacon, not only of freedom, but of progress, of prosperity, and also, of ethical behavior. The research of values that we use in the research process are exactly our American values. So, when we lead in research, we lead with our American values, and that is such a powerful statement to the world.

Senator YOUNG. Thank you, Dr. I think it is also important that this be a fairly broadly bipartisan effort, as China's narrative, emerging from the pandemic is that autocratic regimes are very efficient and effective at dealing with situations like this. We are divided, in many respects, as a country. I think we could be united around this effort.

Very quickly, Dr. Miranda, as my time runs out. We both know how important relations—relationships between academia and front-line Federal customers, and State and local government have been, in our own state of Indiana, in fostering innovation and creating opportunities for commercialization and making our state a unique sort of place where scientists want to live and work on cutting edge projects. In your testimony, you alluded to the success Indiana has had in this domain. So, can you briefly elaborate on how our state's success with research consortia should educate our discussions about regional tech hubs?

Chair CANTWELL. Go ahead, quickly.

Dr. MIRANDA. So, I think what—I think what we are learning in Indiana is that you—if you bring together partnerships where you have the leading research universities, and they are partnered up, as well, with the community colleges, you are thinking about training—not just training PhDs, but training associate degrees who are not going to invent the cybersecurity systems but manage the cybersecurity systems on a daily basis.

So, we have this collaboration between universities—research universities, community colleges, and technical universities. But

then, we also have these partnerships that have been developed with local, regional companies, many of which are trying to make this transition from the sort of, traditional manufacturing economy that existed 50 years ago, to the advanced manufacturing economy. And where universities and colleges and companies have come together, as we have seen in Indianapolis, as we have seen in northern Indiana and in other places across the state, you see this enormous opportunity for creating these regional tech hubs, where the capacity is there. The ground is fertile, the capacity is there, the kind of funding that the Endless Frontier Act would bring, would just light it all on fire.

Chair CANTWELL. Thank you. Senator Blumenthal.

STATEMENT OF HON. RICHARD BLUMENTHAL, U.S. SENATOR FROM CONNECTICUT

Senator BLUMENTHAL. Thanks, Madam Chairman. I have a couple questions relating to early career researchers. In fact, I have sponsored a bill that is called "Supporting Early Career Researchers." The pandemic has up ended life for a lot of people. This measure would create a new post-doctoral fellowship program to support the next generation of STEM talent through the NSF.

And in connection with that measure, which supports careers, especially women and underrepresented minorities, I also have introduced a bill—or I will, Combating Sexual Harassment in Science Act. This legislation was previously championed by myself and Senator Harris—then, Senator Harris. It passed the House last session, but not the Senate. And it would direct NSF to award grants to further study the causes and consequences of sexual harassment. We know that sexual harassment is common to many aspects of American life these days, but in the sciences it seems to, still exist. I have just started reading Walter Isaacsons' book on Jennifer Doudna, which is fascinating. It recounts the story of her being told, early in her career, women do not do science. And we would like to think that those days are behind us, but maybe not.

So, I would be interested in your perspectives. First, Dr. Miranda and Dr. Shaw, do you think sexual discrimination or harassment has hindered careers of women and underserved communities? And do you think we need to do more about it?

Dr. MIRANDA. Thank you for the question, Senator. So, first of all, thank you for the proposal on the post-doctoral program. I think you are right on target of that being a critical thing for us to do for R&D in the United States. Second, I thank you, as well, for your concern in interest in issues of sexual harassment or hostile environments or—I also worry a lot about the awful impact of low expectations of women and minorities, in the areas of science and—especially in science and engineering. So, I do think it is something that is worth investigating.

And you emphasize causes and consequences. I would love for us to supplement that with real, serious evaluation of what kinds of intervention programs actually work to change the local environment, to improve the experience for women. So, we have a whole series of things that we are doing at Notre Dame to create a—to promote a better environment for our minority faculty, for our women faculty, same thing for our graduate students. But we regu-

larly go in and assess, OK, we did these things, how much difference did it make? We asked the people who are most affected by these circumstances, which of these changes, which of these programs made a difference to you?

So, it is both about supporting them, but also about educating people who sometimes—you know, sometimes there is—there is deep intention in what people are saying and doing, and sometimes there is not deep intention. And we have to help them to understand why what they are saying and doing is so destructive for the careers of these—destructive for their individual careers, but also destructive for the university, destructive for science and engineering in this country.

Senator BLUMENTHAL. Thank you. That is a great answer. Dr. Shaw?

Dr. SHAW. I would certainly echo the comments of my colleague and, therefore, will not repeat them. But just to expand on a couple of things related to your question, and actually would also refer back to something that Chair Cantwell said in some of her opening remarks.

Certainly the—I think the pandemic has had a disproportionate impact, in many cases. And I can tell you, on our campus, we are in the midst of conversations as we speak about trying to really re-evaluate things like the promotion and tenure process and the impact that the pandemic has had, disproportionately in ways that we can ensure that our—especially our women faculty, are negatively impacted in a disproportionate way.

I think there is—that opens up a larger conversation, obviously, that we need to be doing all that we can proactively, to be sure that we are not only following Federal legislation—laws, policies, that had been established to eliminate sexual harassment, but be much more proactive in our education programs, so that we can be much more preventive in nature, as opposed to addressing the situations after the fact. And I think—we are certainly open to the conversations that are being held nationally and thank you for your leadership in addressing this vitally important topic. And I think, for the future, the opportunities that we have seen coming out of this terrible situation, actually open up a much larger conversation. So, thank you, Chair Cantwell——

Chair CANTWELL. Thank you.

Dr. SHAW.—for bringing this up today.

Chair CANTWELL. Thank you, Dr. Shaw.

Senator BLUMENTHAL. Thank you.

Chair CANTWELL. Senator Cruz.

STATEMENT OF HON. TED CRUZ, U.S. SENATOR FROM TEXAS

Senator CRUZ. Thank you, Madam Chair. Welcome to each of the witnesses. It seems that a lot of the proposals being considered for combatting China include substantially increasing funding for U.S. research and development. China, for years, has engaged in espionage campaigns at universities and at technology companies, to steal trade secrets and to steal intellectual property. Would all of you agree that the Chinese Communist Party has, and continues

to engage in the systematic theft of American IP and American technology?

VOICE. Yes.

Senator CRUZ. Would you also agree that the Chinese Communist Party has, and continues to engage in the systematic human rights abuses and an ongoing genocide against Muslim Uyghurs?

[Silence]

Senator CRUZ. The intersection of those two threats is a concerning area. Theft alone is not the only problem. The CCP has and continues to use legally acquired technology and stolen technology to carry out some of its most reprehensible activities, like the ongoing genocide of Muslim Uyghurs. If we are going to massively increase the Federal investment in science and technology, as Senator Schumer's Endless Frontier Act proposes, should we not also be taking steps to both safeguard that investment? That is, to ensure that the CCP is not able to steal IP and advance technology developed as a result of the Federal investment—and also to ensure that the technologies that will arise are not sold to the CCP or its proxies, to be used in furtherance of human rights abuses and an ongoing genocide. And that is a question to all the members of the panel.

Dr. DROEGEMEIER. Thank you, Senator Cruz. There is guidance now, from the White House to all Federal Executive Branch agencies to implement policies that will help safeguard our research, in terms of providing guidance regarding disclosures and other types of actions that researchers need to take. Second thing is, educating the community, universities, and so on, in terms of what to look for, how to be prepared, how to evaluate, and so on. But it is—we are only at the beginning stages of this, I think as you well know.

Having been at the White House and getting classified briefings, I agree with you completely. There are some atrocities that—terrible things that are happening. We are very, very vulnerable to this. And so, what we need to make sure that we do is have a balanced approach where we have the openness that is important for research, but we also protect our assets. So, we have a strong offense and a strong defense, at the same time.

So, I think these actions that are being taken, other work that is now underway, and some of the discussions we have had with Congress when I was in the White House, were very, very productive. But I think Congress continues to need to look at this, continually, work with universities, the law enforcement community, intelligence community, and so on. Truly a whole of nation approach, which is the only way I think we can really address this problem.

But I thank you for bringing this up. It is extraordinary important for us and, as a nation, both from a science technology point of view, a competitiveness point of view, national security, but also from the point of view of our American values and what we hold dear.

Dr. MIRANDA. So, I would agree entirely that there are huge adjustments going on across—in universities across the United States regarding how to think about issues of the stealing of intellectual property, how to safeguard things, how do we think about having watch systems and monitoring systems, and all of that. I agree, as

well, that we are, sort of, at the beginning of that process. We are getting better. When I think of how we were 5 years ago compared to how we are now, it is—it is lightyears ahead.

At the same time, I do want to emphasize that some of our most talented graduate students, some of our most talented faculty, people who are contributing in enormous ways to the productivity of the United States, are coming from other countries, including from China, other parts of Asia. My family is an immigrant family, and I was the first one in my family born in the United States. My father spent time doing research that was all about civil engineering research, to contribute to this country.

So, I do want to make sure—I agree with you, Senator, that these issues of espionage, the carefulness with which we have to protect our intellectual property, the systems that we have to build, are so critically important. But I want to make sure we build those in a way where we still welcome the most talented people from across the world, to come and study here and stay here. This is the place where the very best researchers want to live because of the American, democratic system and the values that are here and the way that our research enterprise works.

Dr. SHAW. Senator Cruz, thank you for the question and thank you for diligence on this vital issue. And I can tell you that, from our standpoint, we have worked incredibly closely with the Federal law enforcement agencies, as well as our State agencies, to ensure that we, as my colleague has indicated, have upped our game substantially.

We are now going through a really stringent review process, not only for students and faculty, but also for any visitor that comes to our campus. And those—that—those policies have been developed because of the guidance that we have received with Federal law enforcement agencies. A briefing that was held as late as last week on our campus is a part of the regular series of briefings that we have on potential threats and known information, in that regard.

We are planning on hosting a conference on this very topic, on our campus this fall to address—to be sure that we are providing all of the education and information that is needed to ensure that we are keeping things safe.

Dr. BUTLER. And I will just make one comment on the point. Coming from an industry perspective, and specifically, the work that we do in national security is critically important for us. And it is built into the DNA of our company. And so, as we think about opportunities to engage in a program like this, to take our technology more into the commercial market, we would think about it the same way. We have to maintain some degree of competitive edge. And so, that would—that would mean any technology being built that—through applied research, that is funded to a private company, needs to be protected. And we need to implement the same types of policies that—and procedures, that we have on the DOD side, from an industry perspective, you know, to ensure that we maintain a competitive edge and that that investment that is made by the government is, indeed, protected for the long term.

Chair CANTWELL. Thank you, Senator Cruz. Thank you.

Senator CRUZ. And, Mr. Bonvillian. Can I get his response also? Who is remote.

Chair CANTWELL. We have two other witnesses. If they want to give a quick——

Senator CRUZ. OK, sure.

Chair CANTWELL. If they wanted to give a quick add-in or for the record, either one. We have a——

Senator CRUZ. OK.

Chair CANTWELL. So, yes, let us take their comments in writing and let us go to Senator Baldwin. If—I think Senator Peters will be here to take over the gavel. I am going to go and vote. We are going to continue this effort, because there are lots of questions for members to ask. And I think, after that—after Senator Baldwin, Senator Blackburn. So, with that, Senator Baldwin.

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

Senator BALDWIN. Thank you, Madam Chair. I wanted to start off with a few opening comments before I ask my questions.

As many on this committee know, I strongly support the use of Buy America provisions to boost domestic manufacturing. And I believe that we really need to close gaps in our supply chains. So, I am pleased that the Endless Frontier Act includes a supply chain resiliency program and give the Commerce Secretary the authority to make purchasing commitments, that will further encourage domestic production of critically needed products. In addition, I recently introduced the Made in America Act, with my colleague Senator Braun, to apply Buy America rules to all Federal infrastructure programs, and to a wide variety of construction materials.

As we look ahead to markup and floor consideration of the Endless Frontiers Act, I am going to continue to push for Buy America provisions and language to ensure that the significant funds included in the Endless Frontier Act, support American manufacturers and American workers.

Now, to my questions. I am going to start with a question for Dr. Droegemeier. Successfully university—successful university-led technology innovation and transition have included robust partnering with industry to ensure commercialization and sustainable market applicability. For example, the University of Wisconsin has worked with a local small business to develop innovative electrolyte additives, to increase the importance and safety of lithium-ion batteries. This partnership has brought new products to market using Federal investment. But it has also helped develop a leading research and development capability that could support domestic efforts to discover and validate new battery chemistries and technologies. Currently, most of that innovation, as we all know, and the resulting intellectual property, is happening in Asia by private industry.

I believe that we need to ensure that this legislation builds on this successful model and allows for continued partnership between research institutions and industry. So, Dr. Droegemeier, what, in your view, is the proper role of industry to ensure that the innovations of the universities get transitioned to the market?

Dr. DROEGEMEIER. Well, thank you, Senator, it is an excellent question. In fact, what you just described is a beautiful example of how, you know, research comes to product and product inspires additional research to lead to improvements. So, it is not just a one-way from basic research to product and then, that is where it ends. So, that is very, very important.

I think the role of research in—or excuse me, the role of private companies working with universities is many-fold. One is—one real great value proposition for universities and working with industry is the funding by industry of the research, of the students, of post-docs, and things like that. That is a great, sort of, direct benefit. The other thing is bringing the culture of the private sector to the university environment is a great experiential learning opportunity for students—for graduate and undergraduate students, and so on.

I think the real challenge, of course, arises when we look to license intellectual property, from a university to a private company. That is where, sometimes, things kind of grind to a halt, partly because of differences of culture, difference of value proposition, and so on. And I think some of what would be helpful here, to really streamline that process, is perhaps some of the changes to the IRS revenue proclamations have been talked about in the past that allow greater flexibility in universities to negotiate intellectual property value up front, versus actually having to wait until the IP exists, at the very end of the game. Because really, what we are saying to a private company is, you know, we are going to give you a right to use this, but we cannot tell you how much it is going to cost you. And by the way, please give us your money. That is not, of course, how it really ought to work.

So, I think there are a lot of innovative ways—we have seen this from other universities, like Minnesota and Illinois and Indiana, and other universities that have come up with very creative ways. But I think, systemically, we need to drive some important changes that will really streamline the ability of universities to move their research outcomes to the private sector. And then, continue working with the private sector to develop and innovate on them, and scale up, as you described.

Senator BALDWIN. Thank you. I am going to try to squeeze in one more quick question for Mr. Bonvillian. I am a strong supporter of the manufacturing extension partnership, which delivers a high return of investment for taxpayers, almost $14 for every $1 of Federal money invested. How can MEPs help small and medium manufacturers compete better in the global economy, not only with what their current mission is now, but what would you add on to give them an even more robust role?

Mr. BONVILLIAN. You know, Senator, they do play a very important role. They have become an important part of, kind of, our innovation ecosystem as we start to understand that manufacturing has got to be part of that ecosystem. The MEP task really originated, as you know, in competition with Japan, you know, back in the 70s and 80s. That is really when this program originated. And we move toward trying to meet Japan on quality production. The MEP program did a good job on that, but now we are moving toward bringing in new technologies—new technology advances into the production system. And there is a key role, I think, for the

MEPs in bringing those advances into small and mid-size firms. How can they help bring advanced manufacturing into the SMEs, who are typically slower and more reluctant to adapt that?

And then, second, there is a very important workforce role for the MEPs. We need a lot of workforce training to get those to those advanced manufacturing technologies. And the MEPs can really help their small company members in bringing workforce training, workforce education programs, probably in collaboration with area community colleges, to their members. That can be another major member service.

Senator BALDWIN. Thank you, and I yield back.

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

Senator PETERS. Mr. Bonvillian, it is great to have you and the other folks here testifying. My first question is for you, though, Mr. Bonvillian. In 2019, before the COVID crisis occurred, I published a report out of Homeland Security Committee, which I was the Ranking Member, at the time, and now chairing. I looked at high drug cost in the country and potential supply problems with critical medical supplies. One thing that became very clear through that report, is that we were overly dependent on foreign sources for our supply chain. In fact, if you looked at the precursors of drugs, nearly all the drugs that we used, the precursors that go into those drugs are predominantly from China, but certainly places all across the globe—India and other places. And medical supplies come from the same place. And so, our report concluded that—and this is the conclusion in 2019. When there is a pandemic in this country, we are going to find ourselves in a very precarious situation. Little did I know that that was going to happen just a few months afterward.

So, now this is no longer an academic exercise. This is real, very, very tangible. And we continue to see supply chain disruptions. We are seeing that with silicon chips now, and the impact that it has had. In my state, with the auto industry, is very clear, as well, of the resilience of that we do not have in those chains.

And when you think about critical supplies for national security, we understand that, when it comes to the Department of Defense, we make sure that we make things here in the United States for that. An example, we have a shipyard in Wisconsin. Senator Baldwin was on just before. It is actually in her State, but it is right on the border. Half the workers there are Michiganders that work there. But it is very clear that we understand that we have to be in a position that we will never, ever buy warships from China, or any other country. We make sure we have the industrial capacity in the country to do that, and most importantly we have the skilled workers that are trained and ready to go. That is not something you can build very, very quickly.

And so, we are faced with this incredibly challenging problem and the Biden Administration has proposed creating a new office, at the Department of Commerce, "dedicated to monitoring domestic industrial capacity and funding investment to support the production of critical goods". And certainly, the Endless Frontiers Act presents an opportunity to be able to put that idea into law.

So, my question is, based on your experience, can you comment on how creating an office to help manage supply chain risk, if it is empowered with robust tools to tackle these challenges, could benefit technological innovation in the U.S., as well as domestic manufacturers and the broader economy? Sir, I will start with you, but I am sure other panelists would like to weigh in on that, as well.

Mr. BONVILLIAN. Senator, thanks for the question. I think it is a very important one. We certainly learned from the pandemic that we have got deep supply chain issues in many sectors of our economy. And they also became very apparent in the pharmaceuticals sector. We thought we had, you know, fabulous global leadership of the biopharma sector, but it was a rude awakening when we realized how much of it has now been dispersed at the production stage.

So, an office to do an assessment and to monitor what these supply chain risks are and to understand those in a better level of detail, not just for the primes but reaching down to the tiers of the supplier system, I think, is going to be crucial. Obviously, DOD does a substantial amount of this already in its fields. But even DOD has trouble reaching third tier or even fourth tier suppliers and understanding where those supplies are coming from. So, we deeply need more monitoring.

There is going to be an issue that we are going to have to face, which is that we are not going to, necessarily, have the industrial capacity to fill these gaps. And in certain critical areas, we may want to think about a financing mechanism that would help us to scale up production in some very critical fields.

Senator PETERS. Right. I was going to ask other panelists, but I am running out of time. So, I have another question, but I would love to have your comments. Perhaps we can get that in writing, too, of other support for that.

But, Mr. Droegemeier, this question is for you. As someone who believes in manufacturing and the power of manufacturing in the country as I do, I have found that, unfortunately, we do not have a very coordinated manufacturing policy in this country. In fact, if you look at manufacturing programs, that exist to help manufacturers, there are 58 of those. Which is a great number, but they are spread across 11 different Federal agencies. There is no coordination. There is no one specific voice for manufacturing, to move it forward.

And if you think about our major global competitors, who do a very good job of focusing on manufacturers, the Germans, for example, the South Koreans, others that do it. They get it. They understand you need a coordinated strategy supporting local manufacturing, local businesses, particularly smaller manufacturing. And that is why I have proposed a National Institute of Manufacturing, modeled like the National Institute of Health, that is focused on manufacturing, as opposed to health. But looking at public-private partnerships, how we make sure government is leveraging what private industry can do, let private industry do what they do best, but figure out where the gaps are and how we work in that area.

So, my question is to you is, can you speak to the coordination, or the lack thereof, that exists in Federal manufacturing? And

would something like a National Institute of Manufacturing make imminent sense?

Dr. DROEGEMEIER. Well, thank you, Senator Peters. And I have to tell you, when I read your report on the supply chain for drugs, I was stunned. I mean, that was an eye opener.

You are absolutely right in how you portray this. We do have a lot of things that are out there—Manufacturing USA, the Hollings Partnerships, and so on. And of course, the National Institutes of Standards and Technology kind of—is really, I would say the Federal laboratory to the private sector manufacturers. But we do not really have a whole of government approach. And I think it—you know, it really would make sense to try to coordinate that.

We also do not really have, I think, a national industrial policy, per se. And that is something else that, I think, that you are mentioning, which I have not read what you are talking about. But it just—off the top of my head, it seems to make a lot of sense. Because this is really critical to our future, where the supply chain and things like critical mineral, for which there might be synthetic substitutes, or things more traditional, or advanced manufacturing. It really is a bit part of the future. So, it sure makes sense, as I sit here today.

Senator PETERS. Right. Well, thank you. My time is expired. Senator Blackburn, you are recognized for your questions.

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

Senator BLACKBURN. Thank you, Mr. Peters. And thank you all for this today. We appreciate having the hearing and I—I think that looking at the future and deciding how we move forward is something vitally important. I see Senator Rosen on the screen. She and I had an advanced manufacturing bill that we have worked on now for over 2 years. So, we are pleased to see attention given to this issue. Senator Cortez Masto and I have an entrepreneurship bill that, again, would put more attention on this. And Senator Menendez and I have the SAM-C legislation that, believe it or not, we filed before COVID, which would repatriate active pharmaceutical ingredient manufacturing back to the United States, where these critical supply chains need to be. We need to bring that back. And I do think that is one of the lessons from COVID.

But I would like to hear from each of you, and Dr. Shaw, first to you, Dr. Droegemeier, and then, Dr. Butler. What I would like to look at is workforce, because this is an area where China says they possess a crucial advantage. And it is the reason we have done these various pieces of legislation, to train the workforce to equip them and to have the type jobs here, in advanced manufacturing. So, here is my question to each of you, and then, answer in that order as I have stated. How can the NSF partner with their private sector allies to grow a workforce that will excel in advanced manufacturing capabilities? And what focus should physics programs have on chip fabrication programs, to help with a base of knowledge of chip manufacturing? Dr. Shaw? Go ahead.

Dr. SHAW. Thank you, Senator Blackburn. It is a fabulous question and one that has a number of different aspects that I think we need to be much more prepared to speak to than we are today.

In earlier comments I made, you know, Mississippi State works very, very closely with our community college system in the State of Mississippi and, I believe it is one of the better ones in the nation, in terms of workforce preparedness. And I think part of the recognition is that we need to be able to develop the entire workforce. And so, 4-year institutions and graduate institutions do not need to be just focusing on trying to have everyone graduate with a bachelor's or a PhD, but rather, need to recognize that those kinds of partnerships.

And so, I think the opportunity that we have, through the consideration of the technology directorate at NSF, is not only focusing on graduate degrees or even undergraduate 4-year degrees, but a partnership that goes from high schools to community colleges to 4-year institutions to graduate programs working in a very holistic manner to be able to recognize the workforce needs that are across the entire spectrum. What that also means is that is not unidirectional. It also means that institutions, such as ours, that develop PhDs and post-docs, need to be working very closely with the community colleges and with high school, to be able to be sure that the training that is going on now is the most relevant. And so, if I take advantage of the example that you gave us in chip and advanced manufacturing, we need to be sure that the workforce that is being developed, especially in the community college system, is really adequately prepared for jobs of the future and not jobs of the past.

Senator BLACKBURN. Well, thank you. And full disclosure, I attended Mississippi State. I still serve on the Advisory Board for the College of Business. And, Dr. Shaw, I appreciate the maroon tie. Dr. Droegemeier?

Dr. DROEGEMEIER. Thank you, Senator Blackburn. Certainly, with NSF partnering with the private sector means there are huge opportunities to leverage, in a partnership sense, things like internships and externships where you actually have private companies coming to research facilities at universities. So, sort of, a bidirectional sharing. You know, huge opportunities that the private companies have that you do not find in a university environment.

So, it is, kind of, a multi-generational, multi-institutional, multidisciplinary, sort of—sort of, activity. And I think it is not just about the scientific training that we are doing, but it is about the technological training. The people that are actually building vacuum pumps and doing things, you know, the work that is so critically important—the technological work that does not necessarily involve a degree. That sometimes gets marginalized. But we need a seamless framework, all the way from, say, career-technical, and K–12, and post-high school, all the way through the doctoral programs. And we really do not have that now. There is a lot of—I, kind of, call it 1,000 flowers blooming everywhere, but there are not a lot of lush gardens that are being planted. So, we really need to make sure that we have this seamless framework.

To your point about, you know, Physics departments, and things like that, with regard to chips, I think there is extraordinary innovation happening in things like thin film devices and phononics that is being funded both by NSF and by the private sector. And also, private foundations do a lot of interesting work there. And I think it is so critically important that we continue to innovate in that space because our economy, our national security, and our real quality of life is going to depend on that.

So, I just want to tip my hat to DOE labs, especially Oak Ridge, there in your state, Senator, that has an extraordinary facility for advanced manufacturing. It involves some 60 different companies doing amazing things, all working collaboratively with the national lab and with local universities. It is really a success story and a role model, I believe.

Senator BLACKBURN. Yes, it is, and UT has established Oak Ridge Institute. Go ahead, Dr. Butler.

Dr. BUTLER. Yes, thank you, Senator Blackburn, for that question. And I will just speak to one area of manufacturing that I am familiar with and that is, the manufacturing of data. And that is one of the things that we do at Camgian, is we—we think of manufacturing in the context of data in building AI factories, if you will. And that is the process of being able to take very large volumes of data, apply algorithms to that data to improve operational efficiency for companies, or build the next generation technology firm military.

And one of the things that has been of great—of great success for us in Starkville is the ability to bring in people, in that entire supply chain, to help curate data, to help process that information, to develop the algorithms. The combination of our work with the university to produce very innovative products. Not only—information products I should say. Not only for our military, but also our commercial partners, as well. And that is not just engineers. That is a broad range of people that it takes to facilitate that process from tip to tail. And in doing that in place like Mississippi and places in the center of the United States, I think, is going to be very important for us to be competitive. Because this type of workforce for the future has to be distributed across the country, not just in certain tech hubs in the United States.

Chair CANTWELL. Thank you.

Senator BLACKBURN. Got it, thank you.

Chair CANTWELL. Thank you for your questions, Senator Blackburn. Senator Rosen.

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

Senator ROSEN. Thank you, Chair Cantwell, Ranking Member Wicker, and for all the witnesses for being here today for what you are working. And I do want to build a little bit upon what Senator Blackburn is talking about with advanced manufacturing. We have great bills out there. We need to develop that workforce. It is really important.

But we also need to develop a diverse workforce, right? And so, I am a former computer programmer and I spent decades working in a traditionally male-dominated field. And so, I am thrilled to see

the emphasis on increasing representation in STEM for women and for underrepresented communities and communities of color. And of course, the legislation that we are doing today expands STEM apprenticeship programs and is committed to serving women, minorities, veterans, tribal members, individuals with disabilities, and so many more.

But I think it is important—think about how we measure for success. The data does tell a story. I say this over and over again, if you are smart enough to listen to it. So, how are existing NSF government programs—how are they working to close the gaps in our STEM workforce? Because that is going to increase our opportunities for folks and ensure that employers have the workforce that they need.

So, Dr. Droegemeier, under the OSTP STEM Education Strategic Plan, you prioritize groups that have historically been underrepresented in STEM fields. Do you believe that the OSTP has been successful? How are you measuring that? And where do you think—what do you need to do to fill in—what do we need to do to fill in those gaps, where we are not reaching out and getting people?

Dr. DROEGEMEIER. Well, thank you, Senator, very much. That report that you mentioned actually has three pillars to it. One is a STEM literate society. Another one is creating a STEM workforce, and the other one is, very importantly, the broadening participation dimension.

One thing that I did not get to with I was at OSTP, but I think we need to do as a nation, is really understand our bench strength. We do not really have a good handle on all the individuals that are out there, across all of America, who have the capability, the capacity, the desire to actually come in, if they were given the opportunity. We talk about that a lot but, you know, where are they? Let us go find them. And there are lots of ways that we could—that we could identify them, but we have not really, I think, done that. So, we know they exist, but we really need to go out and identify them and bring them in.

So, increasing the diversity is very important. I think NSF has a whole bunch of different programs that have done this, have worked on this. We are seeing progress. It is not as slow as we all would like. But I think there are innovations, in terms of certain programs that are brining more women and underrepresented minorities, into positions of leadership, where others can be inspired by them and they can help mentor those. But frankly, it is going to take folks like myself and other folks that, you know, are not ethnic minorities, to come in and be champions of these kinds of activities, to help do the same thing.

And so, we really need a whole of nation approach to do this. And I think, pardon me, that is something very important to be happening. NSF finally has a committee called the Committee on Equal Opportunity in Science and Engineering that responds to Congress, submits a report. And they are mapping out a real important national strategy for doing this, as well.

So, I think—I think we are poised to do even more. We have a long way to go yet, but I think we are making progress.

Senator ROSEN. Well, I think you are right. And I would further say that I think we need to collect data before the grants and after the grants, like you said, to build out what our bench strength is.

But I would like to move on quickly to Ms. Rhoads and give you a chance to comment on this, as well, since the W Fund evaluates the inclusivity of women at the companies where it invests. And so, how do you measure inclusivity?

Ms. RHOADS. Well, we are a small and very boutique fund, directed exclusively at companies that are spinning out of research institutions—public non-profit research institutions and I do not think that inclusivity was part of our original mandate. That said, we have been the beneficiary of efforts within universities to promote women entrepreneurship. And so, of our 19 companies, I think that five of them have women in the C-suite or the founding team, and that was a wonderful thing. But it is a big problem and on most of the company boards on which I serve, I am the only woman and there is not a woman in management.

Senator ROSEN. I think we need to work on that, for sure. I only have a few seconds left. I just would like to ask Dr. Miranda, perhaps, if you want to talk about the role that broadband plays—expanded broadband, in leveling the playing field access for American economic competitiveness over the next decade, in order for us to do all of these things. So, perhaps you could just speak broadly to broadband. I guess that is a little pun there. But maybe you could tell us how you think us investing in broadband will help us move all of this forward? Dr. Miranda?

Dr. MIRANDA. Thank you. I think one of the things we need to do, as a country, is make sure that there is universal access and universal high-quality access, to Internet services in every corner of the country. So, the impact of the COVID–19 pandemic is huge on our children—our school-aged children. It is much bigger on children who live in rural areas, or children who live in urban areas that have poor Internet service.

I will tell you; we bought a farm in Indiana. We are 17 miles outside of South Bend. And I do not have good Internet service. It is not because I am not willing to pay for it. It is not because I cannot figure out the technology. I simply do not have good Internet service. I worry daily about all the kids who live in the farming communities around me, such as their ability to continue to make progress in their schooling, under the conditions of the pandemic.

Aside from the pandemic, the whole notion of, if we really want a STEM literate workforce, we want a workforce that reaches the entire country, and not just certain pockets here and there, we have to make sure that Internet is universal—it is like a utility now. And we would not be satisfied with water service that sometimes worked and sometimes did not. Or electricity that sometimes worked and sometimes did not. And that is how we need to think about broadband access in this country.

Chair CANTWELL. Thank you. Thank you. Thank you, Senator Rosen.

Senator ROSEN. Thank you. I yield back.

Chair CANTWELL. Thank you. Senator Scott.

STATEMENT OF HON. RICK SCOTT,
U.S. SENATOR FROM FLORIDA

Senator SCOTT. First, I want to thank Chair Cantwell and Ranking Member Wicker for holding this important hearing. Communist China has shown it is eager to assert its power across the globe, undermine democracy and human rights, violate U.S. sanctions, and prop up dictators. The United States must now recognize that we are in a new Cold War with China—Communist China. And we need to confront this threat using every diplomatic and military option at our disposal. The position we are in today is because of decades of appeasement by Washington politicians, an attitude that is carried forward by many.

My concern is whether President Biden will do what is needed in this critical moment. His words and actions have only emboldened Communist China in his administration's weakness toward General Secretary Xi is gravely concerning. We cannot be naíve in thinking that Communist China wants to operate in the modern world order and cooperate with other world powers.

I have sponsored and supported legislation focused on addressing the security of our supply chains, holding Communist China fully responsible for its genocide against the Uyghurs, enhancing their ability to innovate new technology, and countering Beijing for its unfair trade practices.

This is where our legislative efforts must begin. We need to strategically decouple in critical technologies and out and cut Communist China off from the American economy that it relies so heavily upon, to feed the Communist oppressive machine. Now is the time to display the true resolve of the United States in addressing Communist China's destabilizing actions and finally put policy in place that truly places American interest first.

Dr. Droegemeier, last Congress I joined Senator Portman on his Safeguarding American Innovation Act to provide a better framework to keep Communist China's influence out of our research programs at our universities. Last year, Homeland Security and Government Affairs Committee—Governmental Affairs Committee Subcommittee report exposed the National Science Foundation's inability to protect Federal investments from going to universities or researchers with ties to Communist China's 1000 Talents program. Does this bill include any measures to prevent that?

In addition, is the National Science Foundation equipped to combat Communist China's attempts to steal and spy on U.S. research and intellectual property? And is there any Federal agency that might be better equipped?

Dr. DROEGEMEIER. Thank you, Senator Scott. At the moment, I do not think the bill contains any language regarding research security. With regard to NSF, they have a really wonderful research security officer that they brought on board, I think about a year ago. And the White House issued, in January, guidance to Federal agencies, through a National Security Presidential Memorandum, of a policy to really help safeguard and secure ourselves against foreign threats, broadly defined, especially with regard to things like disclosure of those who are receiving public funds through any Federal agency, disclose certain kinds of things including relationships to talent programs, and so on.

The trick is now, having—it is a uniform policy. The trick is to get it implemented uniformly. I can tell you that NSF takes this very, very seriously, as do other agencies. In fact, they were—NSF and other agencies were putting forth their own different policies and we wanted them to hold off just a little bit, until we, kind of, created a uniform policy. But I do believe that they are reacting very strongly, as are our universities. They are taking actions, many actions, again, to combat these threats. They recognize the challenges.

And so, I think, by working together with the Federal Government, the universities, the private companies, with our law enforcement or national security sector, we are going to make, and are making, tremendous progress. But as I said before you arrived, we are still on the early phases of this. There is a lot of work to be done. And the work that you have done and that other Members of Congress, are greatly appreciated. And I think we still need to really be on top of this.

Senator SCOTT. Thank you. Ms. Rhoads, I have serious doubts that direct government payments to universities is the best answer to meet China's advancing technology, or an efficient return on investment for taxpayers. I come from the business community and my view is, what we ought to do is, if the government wants to accomplish something, what we ought to do is, we ought to bid it out and see who can do the job, and then, hold them accountable if they do not. So, Ms. Rhoads, how can we instead empower, rather than using our universities, empower private sector to create, innovate, and advance technology, so the United States can reduce its reliance on our adversaries, especially Communist China?

Ms. RHOADS. Well, I guess I would just like to first say that apropos of your point, but also something that Senator Cruz mentioned was, while illicit theft of university IP is a huge concern, it is a terrible shame that Congress provides universities with billions for research and not the single digit millions to speculatively patent and protect the resultant IP.

So that now, especially now that we are a first to file country, we are inviting legal theft of our IP. So, that, in and of itself, costs, especially for large universities doing over a billion dollars of research a year, probably a couple million dollars a year. And without those funds, we are inviting other countries to take advantage of the innovation that we create and then, go to colloquia and symposia and, even if we are sophisticated about how to safeguard it without patent funds we discuss.

But to your point, specifically about, I guess, customer-directed or government-directed discovery, I think, while there is a place for that, one of the magical things about university innovation is that these researchers are often volcanos of innovation. And there are so many different kinds of things that they might innovate around and not all of them we can foresee.

So, there is a place for directed innovation programs, with results that we know that we want, and there is also a place for having more open-ended research. And I definitely think that programs where, perhaps, we match industry dollars with non-dilutive dollars will tend to inspire industry and companies and private investors to, depending on the stage of the research, to be willing to ei-

ther invest in the research itself, or its outcomes. Because even when you have a research result, these are so early that they are often too risky to warrant return on investment dollars, unless there is non-dilutive funding alongside.

So, I think there is a variety of forms programmatically that those programs can take.

Senator SCOTT. Thank you. Thank you, Chair Cantwell, for holding this hearing.

Chair CANTWELL. Thank you. Thank you. Senator Luján.

STATEMENT OF HON. BEN RAY LUJÁN,
U.S. SENATOR FROM NEW MEXICO

Senator LUJÁN. First, I want to thank Chair Cantwell and Ranking Member Wicker. I also want to recognize Leader Schumer and Senator Young for prioritizing science and research and development right out of the gate.

New Mexico is home to two world class Department of Energy laboratories, Los Alamos National Laboratory, Sandia National Laboratory, and also, DOD Air Force Research Labs. From the Manhattan Project to the Human Genome Project, our labs have been at the forefront of scientific discovery, to address our Nation's and the world's greatest challenges.

Thanks to our national labs, the United States continues to lead the world in pushing for boundaries in space-based activities. For example, Los Alamos recently played a major role in our mission to Mars. It was Los Alamos who manufactured the fuel that propelled the Mars 2020 Perseverance rover. Sandia National Labs, the first clean room, providing the chips and circuitry that power computing and the internet.

In many of the areas that we are discussing today, artificial intelligence, Quantum information sciences, biotech, advanced manufacturing, high performance computing, and others, the Department of Energy leads America's scientific efforts. The Department and our labs perform open and collaborative science and brings together academics, industries, and a wide range of partners.

Let me offer a few additional examples. Currently, our national labs lead five DOE funded national Quantum information science research hubs. These hubs bring together industry, universities, national labs, NSF, NIST, and others, to strengthen our security, competitiveness, and scientific leadership. Regarding high performance computing and artificial intelligence, our Department of Energy labs currently operate two out of the top three fastest supercomputers in the world, and more coming online through the Exascale Computing Initiative—the Exascale.

These machines serve as the infrastructure that powers the most advanced artificial intelligence in the world. From biotech to nomics, synthetic biology to advanced energy batteries, industrial efficiency and material science, our national labs support collaborative science in these areas and are helping to create the industries of the future. As Congress continues to invest and look forward to the R&D landscape, it must prioritize investments across key agencies and improve coordination across the Federal Government, including at our Department of Energy labs.

I believe that the Committee's decision to focus on our international competitiveness is timely, and our competitors are increasing their investments, as they are looking at our DOE labs as a model. We have already heard from adversaries, including China, who have a deep interest in the United States R&D system. And they have singled out and looked at large scale national laboratories, which are at the center of our scientific capabilities and our ability to meet urgent national priorities. The President of China even characterized Los Alamos, Argonne, Lawrence Berkeley as indispensable momentum for the development and innovation of science and technology.

So, as you can see, I support the Department of Energy's National Labs across the country and I believe that we need to be driving investment in both areas, National Science Foundation, as well as the Department of Energy. And I want to join my colleagues who have shared that with us today.

Dr. Droegemeier, when you were Director of the Office of Science and Technology and Policy, you led efforts to develop a report that examined how to increase American leadership in the industries of the future. What do you see as the role of our national labs and the Department of Energy in this effort?

Dr. DROEGEMEIER. Well, Senator, thank you very much and I think you have really accurately characterized the tremendous role that DOE plays, and especially the 17 national labs. They truly are a crown jewel of America. I think that, in this bill, strengthening the National Science Foundation, because of its unique capabilities of funding the preponderance of fundamental non-medical and clinical, basic research in this country, very, very important.

But certainly, the national labs have a role to play, as well. And in that report you mentioned, the national labs were, kind of, the centerpiece, really, of looking to leverage their tremendous existing capabilities in computing and in facilities and equipment and test beds, and things like that. And really creating an infrastructure and a framework, I would call it, that really goes all the way from fundamental research, all the way to preproduction prototype development, and truly, scale up. And frankly, the national labs are such a characteristic to really help do that.

So, when I think you bring them into the mix with the National Science Foundation, NIST, and other organizations that you mentioned, we truly have the capability to do things in a holistic, collaborative way. And we heard this from Chair Cantwell earlier, that really is the critical thing, in my view, to making this all work for America. So, it truly is not a zero-sum game, as you say. There is plenty of room for NSF enhancement, DOE lab involvement, and perhaps, enhancement, as well.

You know, I think we all just need to recognize that we have got a whole of nation strategy that is unlike anything China can yield—can wield. And so, we really need to get in there and make this work better for America and there are so many things, I think, that we can do better, that do not take massive investments, but they take more collaborations. It is easy to create. It is tough to collaborate. We need to do both.

Senator LUJÁN. Appreciate that. And, Chair Cantwell, I would like to ask unanimous consent to submit, for the record, a letter

from the directors of 17 national labs, which calls on Congress to strengthen and increase investments across the entire U.S. ecosystem.

Chair CANTWELL. Thank you, without objections.

[The information referred to follows:]

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April 13, 2021

The Honorable Joe Manchin
Chairman
Energy and Natural Resources Committee
United States Senate
304 Dirksen Senate Office Building
Washington, DC 20510

The Honorable John Barrasso
Ranking Member
Energy and Natural Resources Committee
United States Senate
304 Dirksen Senate Office Building
Washington, DC 20510

Dear Chairman Manchin and Ranking Member Barrasso:

On behalf of the National Laboratory Directors' Council (NLDC) – comprised of the directors of the seventeen Department of Energy (DOE) national laboratories – we write in response to your recent request for technical assistance on the draft of the Endless Frontier Act.

We commend Majority Leader Chuck Schumer and Senator Todd Young for recognizing the critical role that innovation driven by federal investment in research and technology development plays in competing with China and ensuring U.S. leadership in key technology areas. Their efforts reflect the type of bold and inventive thinking needed to address U.S. international competitiveness and to deliver novel solutions to the challenges facing the nation.

Since their founding in the Manhattan Project, the DOE national laboratories have delivered scientific advances and technology solutions for the nation, while balancing the need for open, collaborative science with the imperative of national security, economic security, and technological superiority. The DOE national laboratories are mission-driven research and development organizations that reside in an important space, with a long-term perspective and operating across the full spectrum from fundamental to applied research to the demonstration and deployment of technologies. This makes them complementary to both academia, which focuses on fundamental research and the advancement of knowledge, and industry, which is primarily concerned with the development and application of research outcomes in the near-term. As such, we believe the DOE and its national laboratories can make significant contributions to out-competing China.

We recommend that the Endless Frontier Act or other related legislation embrace a broader approach to advancing the nation's international technology leadership and economic competitiveness by investing in and strengthening the entire U.S. innovation ecosystem, including the ongoing work and additional initiatives of DOE and the national laboratories across the Act's key technology focus areas. Specifically, we recommend a separate, substantial, targeted investment in research for DOE and the national laboratories to advance key technology areas in coordination and collaboration with the National Science Foundation (NSF), and to fund increased support for and access to world-leading user facilities stewarded by DOE and utilized by NSF-supported scientists to advance scientific discovery and technology development. We share the view that providing much greater resources across the innovation ecosystem is the best way to achieve the Senate's goal of bolstering our competitiveness with China, and indeed with the rest of the world. Our distributed, multi-agency, multi-stakeholder approach to science and technology has served the nation well throughout its history. This approach brings diverse viewpoints, wide ranging capabilities, creativity, and ingenuity to science and technology in a way no other country can match.

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NSF, like DOE, is an essential component of the nation's innovation ecosystem and an important partner to the DOE and its national laboratories. NSF is the only federal agency charged with the promotion of scientific progress across all science and engineering disciplines. The research funded through its rigorous peer review process is vital to the public interest and has led to transformative discoveries that have reshaped our world. Through its sponsorship of cutting-edge, university-based research, NSF supports the education and training of the nation's scientists, engineers, and teachers and the next generation of new ideas.

Complementing these efforts, DOE assembles and nurtures multi-disciplinary teams of scientific experts to meet federal needs and address national priorities by attacking R&D challenges at scale. DOE does this by supporting university research, industrial partnerships, and a network of 17 national laboratories that are responsible for cutting-edge science and technology research and development. The national laboratories are also responsible for constructing and maintaining one-of-a-kind, world-class research capabilities that are leveraged broadly by over 36,000 university and industrial researchers every year.

For example, the DOE Office of Science maintains and operates 28 user facilities at its national laboratories across the country. These major pieces of scientific infrastructure range from advanced supercomputers and particle accelerators to large neutron and x-ray light sources and specialized facilities for nanoscience and genomics. These user facilities are vital tools of scientific discovery and provide unique and often world-leading capabilities. The National Synchrotron Light Source II at Brookhaven National Laboratory, for instance, is currently one of the brightest X-Ray Light sources in the world and enables discoveries in a broad range of fields, including biomedicine, energy storage and conversion, quantum technology, and molecular electronics.

DOE and the national laboratories provide access not only to these major scientific tools but to dedicated experts who help tens of thousands of researchers funded by NSF and other agencies, as well as industry users, conduct scientific experiments with these powerful tools. Access to these facilities is awarded based on merit review of proposals. Technical upgrades are underway at many of these facilities to ensure that they will remain at the international forefront. However, operations of these facilities are highly budget-constrained at the same time that they are in such high demand that they are already oversubscribed in most cases by a factor of two to five. The additional funding proposed for NSF as part of the Endless Frontier Act would place further demand on these valuable tools. DOE would require a complementary and commensurate investment in the tools, capabilities, and staff support for these user facilities to enable the greater volume of high-impact research and development envisioned by the Endless Frontier Act.

DOE and the national laboratories are also at the forefront of advancing emerging technologies, including both fundamental and use-inspired research and development of applied energy technologies. The national laboratories also maintain a complex of energy technology demonstration facilities, such as the Manufacturing Demonstration Facility at Oak Ridge National Laboratory and the Wind Dynamometer Test Facilities at the National Renewable Energy Laboratory, that are critical to the advancement and derisking of U.S. technology innovations.

Coordination between DOE and NSF is essential to leverage each agency's respective strengths to maintain U.S. leadership. In reviewing the key technology focus areas enumerated in the Endless Frontier Act, the National Laboratory Directors' Council identified significant DOE investments at national laboratories and universities in nine of the eleven focus areas. We would welcome an opportunity to discuss with you the full

portfolio of these efforts and ways that the capabilities and expertise of the national laboratories should be leveraged to support increased investment in these areas. We include four illustrative examples here:

- In quantum computing and information systems, the national laboratories are leading five National Quantum Information Science Research Hubs – each with diverse members that include American industry, universities, and national laboratories – funded by DOE, thanks to bipartisan congressional support for the National Quantum Initiative and subsequent appropriations. These centers are part of a coordinated, multi-agency effort with the NSF and National Institute for Standards and Technology, and serve as an excellent example of a complementary, multi-agency approach.
- On high performance computing, semiconductors, and advanced computing hardware, the national laboratories operate two out of the top three of the world's fastest supercomputers with more coming online later this year and early next through the Exascale Computing Initiative. And by nature of their design, these exascale systems will also represent the most powerful artificial intelligence machines in the world. In addition to the supercomputers, the national laboratories have some of the world's leading experts in computer science and advanced mathematics, which is crucial to leveraging each new generation of bigger and better computing capabilities through advanced software development. This is a key area where DOE, through Office of Science and the National Nuclear Security Administration (NNSA), and the national laboratories have long maintained the delicate balance between the need for open science and imperative for national security as stewards of the nation's nuclear deterrent.
- In advanced energy, batteries, industrial efficiency, and materials science, DOE – across nearly its entire portfolio – is the lead agency for the nation in driving innovation through research and development efforts at national laboratories and universities in partnership with industry; capability development and stewardship, especially at the national laboratories; and supporting robust public-private partnerships.
- In biotechnology, genomics, and synthetic biology, DOE's national laboratories possess one of the world's greatest collections of research facilities, international scientific leadership, and other assets focused on non-human biology for energy, environmental sustainability, and biomanufacturing. The Joint Genome Institute at Lawrence Berkeley National Laboratory and the Environmental Molecular Sciences Laboratory at Pacific Northwest National Laboratory are among the world's most sophisticated research facilities focused on biology by design to address climate change, clean energy, and environmental sustainability. These facilities are utilized annually by thousands of users and tens of thousands of data users. Over the past year the National Virtual Biotechnology Laboratory was rapidly organized to bring DOE and NNSA scientific user facilities, additive manufacturing capabilities, and high-performance computing to bear addressing the threat posed by COVID-19.

In regard to all the key technology areas, the DOE and its national laboratories have the talent and the mechanisms to analyze the dual use implications of new technologies, and the charge to alert government authorities and policymakers to over-the-horizon technical threats that may impact American lives and underpin future U.S. economic competitiveness. The NNSA has been analyzing and identifying threats for decades with respect to U.S.-developed nuclear materials and technologies. All national laboratories have been doing the same with respect to artificial intelligence, biotechnology, and high-performance computing. These at-the-ready capabilities can be expanded and re-tasked as necessary to address ongoing and

emerging threats, and are vital to advance research frontiers in such a way as to assure our national security and economic competitiveness.

Finally, we recognize that the draft bill makes national laboratories eligible for grants from the new NSF directorate created by the bill. However, historically and currently, the national laboratories as Federally Funded Research and Development Centers are not considered eligible to apply for funding from the NSF, nor do we believe it is appropriate for national laboratories and universities to compete head-to-head for awards except through diverse, multi-institution consortia.

Thank you for requesting our input, and for your part in authorizing and overseeing the important work of the Department and our laboratories. Congress has made significant investments in DOE and the national laboratory complex that address most of the key technology areas outlined in the legislation. We look forward to working with you to ensure that DOE's national laboratories receive the resources necessary to execute additional work in support of the goals of the Endless Frontier Act while also maintaining its stewardship and mission obligations to DOE.

Respectfully,

Adam Schwartz
Director, Ames Laboratory
Executive Committee, NLDC

Paul K. Kearns
Director, Argonne National Laboratory
Executive Committee, NLDC (Ex Officio)

Doon Gibbs
Director, Brookhaven National Laboratory
Chair, NLDC

Nigel Lockyer
Director, Fermilab

John Wagner
Director, Idaho National Laboratory

Michael Witherell
Director, Lawrence Berkeley National Laboratory

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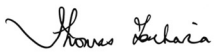
Kimberly S. Budil
Director, Lawrence Livermore National Laboratory

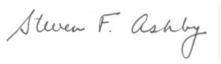
Thomas Mason
Director, Los Alamos National Laboratory

Brian Anderson
Director, National Energy Technology Laboratory

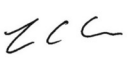
Martin Keller
Director, National Renewable Energy Laboratory
Executive Committee, NLDC



Thomas Zacharia
Director, Oak Ridge National Laboratory



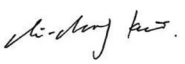
Steven Ashby
Director, Pacific Northwest National Laboratory



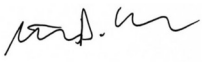
Steve Cowley
Director, Princeton Plasma Physics Laboratory

James Peery
Director, Sandia National Laboratories

Vahid Majidi
Director, Savannah River National Laboratory



Chi-Chang Kao
Director, SLAC National Accelerator Laboratory



Stuart Henderson
Director, Thomas Jefferson National Accelerator Facility

Senator LUJÁN. I yield back, thank you.

Chair CANTWELL. And certainly, agree that whatever investments we make should, just as we did with COMPETES, include something for our national labs and the great work that they do. I think, unless Senator Lee is joining us remotely, I think we next have Senator Markey.

STATEMENT OF HON. EDWARD MARKEY,
U.S. SENATOR FROM MASSACHUSETTS

Senator MARKEY. Thank you, Madam Chair, very much. Yes, this is just such an important hearing, and it really just goes to our future, the future of our country. Research is a field of dreams from which we harvest the findings that give hope that we are going to make the huge breakthroughs in just so many critical areas of our existence. So, thank you for having this very important hearing.

This committee, last year actually, passed out a piece of legislation that was authored by myself, Senator Tillis, Senator Collins, and Senator Peters. And that authorized $25 billion to be used for research at NIH, at DOE, at NOAA, at NIST, at EPA—across the board. All these agencies that had seen real fundamental hits made on their personnel and on their ability to do research. And it did pass out of the Committee last year and I would like to see it included in any package that moves this year, obviously. And just wondering, Mr. Bonvillian, if you could agree that the Endless Frontier Act should include the provisions from the RISE Act, we called it. That was Research Investment to Spark the Economy Act, which has already passed out of our committee. Do you think that should be included in the Endless Frontiers Act?

Chair CANTWELL. Senator Markey, who was that directed toward?

Senator MARKEY. Mr. Bonvillian. Mr. Bonvillian.

Chair CANTWELL. OK, thank you.

Mr. BONVILLIAN. Can you hear me now?

Senator MARKEY. Yes.

Mr. BONVILLIAN. I just want to note, Senator, that the university community and the university associations have been very strongly supportive of your RISE legislation. The whole research system took a major hit during COVID. Lots of research projects had to be cut back. Graduate student careers were all pushed back a year. Faculty and researchers were affected in many, many ways. So, I know that there is very substantial support for this legislation, and I am sure that the Committee, having passed it out already, will be happy to reconsider this here.

Some of my colleagues here on the panel are university provosts, so I just want to note they may have some thoughts about this, too.

Senator MARKEY. Is there anyone who would like to add their comment on it, who is a university provost?

Chair CANTWELL. You might have to tell them a little bit about the—what was in the bill, Senator.

Senator MARKEY. OK, well, I think—I heard from Mr. Bonvillian. I think that is great and speaks to what the university community, writ large, was interested in when they endorsed that legislation last year, as it came out of our committee. And so, I thank you for that. And again, it is just research funding across the board.

And I would like to just ask Mr. Bonvillian one final question, and that is, a piece of legislation called the Cyber Shield Act, which would create a program for IOT manufacturers to voluntarily certify that their products meet industry-leading cyber security benchmarks. They can display them with a Cyber Shield label, that will help consumers to identify and purchase more secure technology for their homes. Do you think makes sense, Mr. Bonvillian, as something that we should be including in this legislation?

Mr. BONVILLIAN. Senator, there is a genuine problem here, obviously, as we are all understanding, about cybersecurity and Internet security. There is an increasingly deep societal set of issues here and it obviously affects consumers and the public in a profound kind of way.

So, you know, one of the things about research and the development of technology is, technology is always a two-edged sword, right? There are going to be great things that come out of technology, but there are going to be problems as well, as you have recognized in this legislation. And we have got to anticipate that, make sure that we are developing solutions in parallel, as the technology evolves.

So, one of the obligations that we are going to have, if this legislation moves, is to ensure that, in these critical technologies, the other side of that two-edged sword is being anticipated, thought about, and responded to. So, your Cyber secure Shield legislation is, kind of, part of that story, I believe.

Senator MARKEY. Oh, thank you. Yes, so we have to build in the safeguards, the seatbelts, right up front, as we move forward. There is a Dickensian quality to all these technologies. They are the best of technologies and the worst of technologies, simultaneously. They are only as good as the human values that we animate them with. And so, having this kind of a rating system for a Cyber Shield gives consumers the ability to protect their families.

So, I thank you, Mr. Bonvillian, and I thank you, Madam Chair.

Chair CANTWELL. Thank you, Senator Markey. For the witnesses, we are getting to the end, but we do have a very large committee. We also have a vote going on. But we will try to get through this in the next 15 minutes, or so. So, Senator Lee.

STATEMENT OF HON. MIKE LEE,
U.S. SENATOR FROM UTAH

Senator LEE. Thank you, Madam Chair. Thanks to all of you for joining us today. Today's hearing is on the Endless Frontier Act and it is part of an important debate about our country's future and about our country's mobilization to defend ourselves against China's threat to the U.S. homeland, to a free and open Indo-Pacific, and to our democratic allies abroad.

Properly counteracting the Chinese Communist Party is necessarily going to require the United States to carefully assess the threat and to consider how best to respond. Rushing to enact government policy without review, and without adequate debate, could really harm American interest. And if we are not careful, it could end up having the opposite of the effect we want, one where we harm our own interest and that harm, somehow endures to the benefit of China.

It is important for us not to lose sight of how American values, values of freedom, innovation, entrepreneurship, market-based solutions, our commitment to free market economics, make us a global leader. As we have this conversation, I think we should not abandon these principals in some sort of an attempt to compete with China by trying to beat China at China's own game. We will lose that effort. But we will win efforts if we focus on what has fostered the development of the greatest civilization the world has ever known.

China's communist approach centralizes the power of the state and it harnesses that power, in order to control its own people. What China pursues is nothing less than, and nothing more than an authoritarian command and control industrial policy. One in which ideas and innovation are subject to the whims of the Communist Party officials, themselves. So, we should not try to counter China by imitating China. It simply does not work.

Dr. Droegemeier, I am concerned that our response to increased Chinese investment in R&D is, or might become, just to outspend China. Will, outspending China, or being like China, in that regard, through Federal Government, actually counter the Chinese threat?

Dr. DROEGEMEIER. Thank you, Senator Lee. I think—I think we really, certainly, do not want to operate like China. We have our American values, that you so thoughtfully expressed. But what I love about research is, they are very much the same as research values—ethical behavior, mutual respect, and so on—bold thinking.

No, I do not think outspending China—in fact, I think the key thing is that, as we have talked about before, we really have to do things differently. I think just pouring a lot of money into existing frameworks is not going to get us there. Now, we do need to increase funding. There is no question about that. But I think to—you know, one of the things that we talked about with the bill is to be smart and to look at creating frameworks for allowing collaboration and interaction across all the sectors of our research enterprise in ways that we do not now do. And frankly, I think the pandemic gave us the best use case for how we can accelerate, how we can really not be completely hands tied behind our back in terms of certain regulations that really impede progress and do not provide value.

And so, I think, leading with our own values, but also doing things smarter than China, better than China, and with increased funding, I think that is really the solution for success. It is not easy. But they take the easy route by just doing stuff and without regard to a lot of things that we care deeply about. We do not have to forsake those things. We can actually use our capabilities in just the opposite way, I think, to really lead the world, and with our values shining brightly.

Senator LEE. That is a fair point. So, following up on that, how much should the U.S. Government—the Federal Government of this country, how much should it itself, not the private sector in the United States—how much should the Federal Government spend on R&D? 100 billion? 250 billion? Why not a trillion dollars? Is there a point at which Federal Government spending, in this area, becomes counterproductive?

Dr. DROEGEMEIER. That is a great question that I have had. As a scientist, I like look at data and say, OK, what do we really need? What are the right numbers? And I think, you know, we do not really have, in this country, a comprehensive science of science policy framework to go by. I think we take the baseline budget and say, let us add on top of it. What is it we really need? We do have some hard data. NSF now fails to fund about $4 billion of research every year that it could fund, if it had the funds to do it. So, that is an important data point.

So, I do think that it is important to continue investing in the fundamental discovery research that really is a primary domain of the—of the Federal Government, and then, work together with these other sectors. I think that question really needs some serious thought, to say, what is the right number. I do not, honestly, know what it is. And I think we, as a nation, need to come to grips with that and we can.

I think we have the tools to really understand what it would take to do certain levels of—of, you know, competitiveness or achievement, if we have a long-term plan, which we also do not have. We need a 50-year horizon, look ahead in this country. China thinks very, very long-term. We think the next budget cycle. We have got to think beyond—I know it sounds weird for a meteorologist to say this. We need a 50-year—not a forecast, but a projection. An arc that allows us to think about America over that 50-year time period.

Senator LEE. Madam Chair, I see my time has expired. Can I just ask just one very brief follow-up question to that?

You would agree then, that there is a point—I am not sure where it is, but there is a point beyond which Federal Government spending might well be crowding out private investment? And I think it is safe to say, is it not, that it would end up spending money less efficiently than the private sector would?

Dr. DROEGEMEIER. I think that is right. Plus, it also can change, I think, human behavior and expectations. It might make people far less hungry to come up with innovative ideas. We do not want to do that. We want people to be hungry and to work really hard for the money they get. That is one of the hallmarks of our system. But there is a balance point of that and then, starving people because there is not enough funding available.

Senator LEE. Thank you. Thank you, Madam Chair.

Chair CANTWELL. Thank you, Senator Lee. Senator Warnock.

STATEMENT OF HON. RAPHAEL WARNOCK,
U.S. SENATOR FROM GEORGIA

Senator WARNOCK. Thank you so much, Madam Chair. I think it is pretty clear that we are not invested nearly enough in our country's Federal research and development. And as a result, we are seeing the impact of that. Certainly, I am seeing it in the State of Georgia. West Point, Georgia is home of Kia Motors, the only manufacturing facility for Kia in our country. It is a factory that runs 24-hours a day. It employees more than 2,700 people, and it produces 340,000 vehicles per year. Yet, last week, the Kia factory almost had to suspend production, for 2 days, due to the global semiconductor shortage.

The Endless Frontier Act would increase research at the semiconductor design and fabrication, as well as protect America's supply chains, which is also a national security issue. So, for America to remain competitive, we have to build public and private partnerships, and we have to invest in research and development.

Mr. Bonvillian, how would investments in regional innovation hubs take on some of our toughest challenges, such as the global semiconductor shortage, as well as other issues that can potentially cripple our manufacturing, in a state like Georgia? You are muted.

Mr. BONVILLIAN. Senator, as you understand well, we need to get through a series of stages before we get to that magical production moment, in a way. And the role of regional innovation is the seed bed where product, you know, can actually materialize. You take the prototyping that has come out of the earlier stages, including through these university development centers and the test beds that the bill envisions. But, you know, it is like making an airplane wing. Somebody has got to put that wing onto an airplane, and somebody has got to put the airplane into an airline.

The regional focus in the bill enables us to start building innovation in-depth. It should not be focused on a few centers. We need to broaden that innovation base across the country. And a study that I cited in my testimony indicates there is probably 102 different regions with the necessary assets of university research, of community colleges and educational institution mix, of strong businesses, both small and large, of committed State and local government support, that can build these ecosystems that we are going to need for regional innovation.

So, I think that is our key element in this system that we need to build here, if we are going to get to that production moment. And it is true, not simply in fields like semiconductors. It is true in the range of critical technologies that we are discussing here. So, the regional piece, I think, is a very important element.

Senator WARNOCK. Thank you so much. Another provision of this Act is that it will dramatically increase the amount of Federal funding and R&D available to colleges and universities. But we know that all colleges and universities are not equally equipped to apply for large Federal grants. Historically, such funding has disproportionately accrued in a small handful of large universities with very large endowments.

A recent report from the National Science Foundation found that just 30 institutions account for 42 percent of all R&D spending by colleges and universities across America. And none of these 30 institutions were HBCUs—Historically Black Colleges and Universities, or minority-serving institutions. When the National Academies of Science examined the underrepresentation of people of color in STEM fields. They concluded that HBCUs and minority-serving institutions play a critical role in training students of color for careers in STEM. They also recommended that the Federal Government offer grants to HBCUs and minority-serving institutions to help build institutional research capacity, so that they can compete for these large grants.

I would like to ask Dr. Droegemeier, what is the role of HBCUs and MSIs in educating America's STEM workforce? And do you see

that as a big part of the issue around research and development and its impact on supply chains?

Dr. DROEGEMEIER. Thank you, Senator Warnock. Absolutely. MSIs, HBCUs have a great role to play, and I think, in fact I made a couple of suggestions in my written testimony in that regard. The first one was that, as you say, a lot of these institutions did not have the research administrative infrastructures to support increased funding by sponsored programs—externally sponsored research programs. So, I think some of the funding in the bill ought to be directed to that purpose. Because, in some cases, the worst thing you can do is provide a lot of additional funding but not provide the underlying infrastructure to manage it. And then, you open up those very institutions to vulnerabilities of mismanagement of funds, or whatever, through no fault of their own, simply because they do not have the resources necessary to do it.

The second point is, a lot of those institutions have very strong histories, very positive histories of teaching and additional research funding could change, fundamentally, some of their philosophies about how they handle, you know, promotion and tenure guidelines, and things like that. So, I think the presidents and chancellors of HBCUs, which meet together as a group every year, they and others need to be brought into the conversation early on to really understand how the cultures of their institutions might change, were they to get involved in additional research.

And certainly, with regard to supply chain, as you mentioned, it is a very, very critical factor, and we need all hands on deck. And I can tell you, I have worked with a lot of HBCUs and minority-serving institutions, and also in small institutions throughout the country. And when you go visit those places, you find extraordinary talent doing extraordinary things. So, by bringing them all to the table, I think we, as a Nation, will realize a much greater return on the investment of our talent than we are right now, simply because some of these institutions, historically, have not been major players in research, but have the capability to. We just need to help empower them.

Chair CANTWELL. Thank you. Thank you. We have to go to Senator Lummis. Thank you so much, Senator Warnock.

Senator WARNOCK. Thank you.

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

Senator LUMMIS. Thank you, Madam Chairman and thanks to our panel. Really appreciate your time today. Mr. Shaw, one of the concerns I have about NSF funding, in general, is the disparity in funding allocation. In 2018, seven states received half of all NSF funding and the bottom 10 states shared 3 percent of funding. So, to put a finer point on it, California, in 2018, received $774 million from NSF and Wyoming received $49 million. So, what can we do to alleviate this disparity and make sure rural America has a fair shot at funding?

Dr. SHAW. Senator, thank you for the question. That is certainly a great question and I spoke to that in some of my opening remarks and have expanded on that in some of the written comments that I have provided.

I think you have laid your finger on something that really is critical if we are going to be able to move forward as a Nation. The opportunity that we see in the—some of the proposed language that I have seen, that highlights the EPSCoR, the Established Program to Stimulate Competitive Research, is very heartening to see. And as a participant in that in our state and, frankly, as the previous principle investigator for our statewide EPSCoR program, I can speak very directly to the benefits of that program.

I think we need to be looking at how we can use those EPSCoR funds and funds like that, to be able to use it to enhance the research infrastructure in our states. And frankly, one of the things that we have seen in our state is, that it also enhances something else that we have talked about a lot during the hearing today, and that is collaboration. All of the research institutions in the States, for Track 1 programs within EPSCoR, are required to work together. And that is something that has been extraordinarily beneficial in our State, and I know in all of the other 28 jurisdictions that fall within the EPSCoR program.

I think, above and beyond that, we need to be thinking very broadly about some of the other programs that are outlined in this, and that have been under discussion for quite some time. Everything from undergraduate research programs that are very strongly supported by NSF, but I think we need to be thinking about that in regard to the technology directorate and ways that we can involve undergraduate students much more directly and broadly. All the way to some of the support that has been suggested that we provide for, not only PhD students, but in particular, post-graduate programs.

Senator LUMMIS. Thank you, Dr. Shaw. In a former life I was on University of Wyoming's EPSCoR coordinating committee. So, when you are talking about EPSCoR, you are near and dear to my heart.

Mr. Droegemeier, the Endless Frontier Act plans to establish regional technology hubs to focus on research and commercialization of new and emerging technology. Now, keeping in mind the disparity in NSF funding, it is important to ensure geographic diversity in the placement of these technology hubs, too, to see that rural states, like, Wyoming, Montana, and North Dakota receive some locations. So, how can the bill be updated to ensure rural and frontier states will host some of these technology hubs and not just spoked around the big cities and the big universities?

Dr. DROEGEMEIER. Well, thank you, Senator. Coming from Oklahoma, I could not agree more. As I mentioned, these sorts of states have tremendous capabilities and, in fact, I think we talked earlier about expanding. I think it said at least one of those would be in an EPSCoR jurisdiction. And as Dr. Shaw just mentioned, the one beautiful thing about EPSCoR, as you well know, it brings the entire state together. All the different institutions working together. So, I would see that they would be especially competitive to put forth proposals to create these innovation ecosystems. And frankly, if you look up and down the middle part of the country, at all the—you know, all the way from the Dakotas down to the Gulf Coast, you find some of the major corporations in America, not just energy companies, but Tyson Foods, and other companies like that.

So, I think we are—and of course, they depend a lot upon technology. So, I think those states are really poised to do this. And I think the bill needs to be stronger, as we heard suggested earlier, to bring in some of these other jurisdictions that do not historically perform as well, as far as sponsored research to do these innovation hubs. It really should not be a one size fits all program, frankly. A different—a hub that is going to be, say, in one part of the country is not going to look like a hub in another. And so, they ought to not really be competed against one another, but competed against what is best for America.

Senator LUMMIS. OK. Loved your answers. Thank you so much. I yield back.

Chair CANTWELL. Thank you, Senator Lummis. Excuse me. Thank you, Senator Lummis and I think that concludes our questions. I just want to thank our witnesses, both here in the Capitol—I mean, here in the building and those virtually attending. It was such a great discussion today. We know there is a lot of depth and breadth here to cover.

We ask you to respond to questions that members will be submitting in writing. I plan to submit some. I think Ms. Rhoads made a great point about whether we should be funding patent filings, or not, for universities. I think that is a really great way to protect our intellectual property, and maybe you can give us comments on that.

We had a lot of conversations about STEM. I am definitely going to submit something to ask about where we really should we be with STEM funding, because you have all made suggestions from fellowships to diversity, and I think this is one aspect of it we need to focus on. And obviously, we need some more work on the regionalism component.

But I cannot thank you enough. This has been very illuminating and I can see from this panel, which I think does represent diverse geography, as well as diverse interest. I think if we left it to the people who were on this panel, we could come up with a resolution to our questions and move forward on getting this legislation on the Senate floor.

So, thank you very much. The hearing record will remain open for two weeks, until April 28. Any Senators who would like to submit questions for the record, please do so by the 21st. Then, we ask witnesses to respond to the Committee by the 28th. But that concludes the hearing. Thank you again for everybody's participation. We are adjourned.

[Whereupon, at 1:07 p.m., the hearing was adjourned.]

A P P E N D I X

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARIA CANTWELL TO DR. KELVIN K. DROEGEMEIER

Question 1. Fundamental research has enabled the technologies that drive the modern world, from the Internet and web browsers to GPS navigation, and led to the creation of a new digital economy. What steps should NSF take to protect its basic research portfolio while ensuring that we continue to create and prepare for technological change?

Answer. Your points are exactly correct, and as I mentioned in my written testimony, oral testimony, and response to questions at the hearing, it is crucial NSF not lose its foundational mandate and exceptional track record of funding curiosity-driven discovery (aka basic) research. I do believe, however, NSF can indeed continue this history-changing mandate while also embracing a larger role within its organization of supporting additional use-inspired research that is linked to specific areas of technology vital to American interests (as mentioned in my written testimony, NSF already supports use-inspired research in all of its seven directorates).

To your specific questions about actions NSF can take to protect its basic research portfolio in balance with supporting use-inspired technology research, I recommend the following:

1. To the extent NSF has the flexibility to do so via funds appropriated within its Research and Related Activities (R&RA) Account, NSF should increase significantly funding of the other seven directorates to a) support the $4 billion or so of unfunded projects judged each year to be as meritorious as those which are funded, b) support new projects within the other directorates that are especially of high intellectual risk and potentially high societal reward, c) create a new Industry Graduate Research Fellowship that is funded 1/3rd by NSF and 2/3rds by industry, thereby greatly increasing the flow of students into the system. Importantly, these fellowships would not be of the traditional nature in focusing solely on creating future researchers and faculty members, but rather have a broader perspective of helping train students, via the industry and other sector engagements in the Regional Technology Hubs, in entrepreneurship, IP, business practices, etc. That would set them apart from traditional NSF Graduate Research Fellowships and be highly complementary to them.
2. NSF should make the new directorate specifically dependent upon basic research funded by other parts of the Foundation. Additionally, NSF should require the new directorate to spend a significant fraction of its budget funding work in partnership with other directorates, and also partner with external interests, such as private sector companies at the institutional strategic level, to leverage Federal resources and create a true, tightly knit multi-sector ecosystem. This will ensure the new directorate is always dependent upon basic research in other parts of NSF and does not become a self-sufficient entity unto itself.
3. To improve the engagement of all parts of America in basic research, NSF should undertake an effort to create a strategic plan for EPSCoR that is bold and contextualized by a new directorate and the various things the bill seeks to accomplish. Given NSF's strong capability to drive change in the community, a stronger and more visionary EPSCoR program at NSF likewise would create needed change in associated universities, both tangible and culturally.

Question 2. What would you describe as the key characteristics that NSF now requires to be successful?

Answer. This is a good and very important question, and I believe NSF, going forward, needs to be an organization that (arbitrary order):

1. Does not rest on its laurels or is driven by historical inertia, but rather leverages its powerful reputation to try new things, such as innovative frame-

works for partnering across all sectors of the research ecosystem (industry, academia, for-profit companies, and non-profit research foundations);

2. Funds bold, curiosity-driven research that might overturn established paradigms but, if successful, could be transformational—balanced with support of more use-inspired research linked to specific societal problems;
3. Is adroit at moving certain types of research outcomes into products and services for the benefit of society;
4. Sets the standard for innovative partnerships with private industry at the institutional level, *i.e.,* via direct interaction between the NSF Director and leaders of various companies;
5. Adjusts its internal policies and procedures (*e.g.,* budgetary thresholds requiring NSB approval) in ways that allow it to move more quickly in designing and executing programs;
6. Has employees, up and down the line, who think as boldly and transformatively as NSF and NSB leadership;
7. Engages effectively with its international counterparts, creating bold new alliances that leverage funding, facilities, and human capital;
8. Leads among Federal agencies in its approach to securing research assets in a manner balanced with the open sort of environment—including supporting researchers who come to America to study—that is needed for America to continue leading research globally;
9. Sets the standard for broadening participation in science and engineering research, education and technology, both within NSF and within the external community, in the most expansive way in which the phrase can be defined;
10. Sets the standard for reducing administrative workload on researchers and eliminating compliance activities that show no real value; and
11. Promotes very strongly the values of research (*e.g.,* honesty, integrity, collaboration, sharing, openness, rigorous civil debate, etc), the importance of adhering to them, and the manner in which they reflect American values as a means for promoting America as a collaborative partner around the world.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY THE HON. SHELLEY MOORE CAPITO TO DR. KELVIN K. DROEGEMEIER

Question 1. The Established Program to Stimulate Competitive Research (EPSCoR) Program is a critically important program for small, rural states like mine. EPSCoR helps states like mine build research capacity. Even during the COVID-pandemic, funding through EPSCoR has allowed West Virginia to continue with various research projects in areas ranging from advanced materials to robotics. How can Congress better leverage the potential in EPSCoR jurisdictions?

Answer. Coming from an EPSCoR jurisdiction and having chaired the committee that developed Oklahoma's EPSCoR Strategic Plan, I agree completely with your statement about the importance of EPSCoR. Unfortunately, studies have shown that, although EPSCoR has enabled states such as West Virginia to keep pace with non-EPSCoR states (*e.g.,* California, Massachusetts, Washington, Illinois), *it has not narrowed the gap between them.* EPSCoR's fundamental role is to increase the competitiveness of its jurisdictions, which I interpret to mean *improving their capabilities relative to their peers. That is not happening for many reasons.*

I believe Congress can be helpful by taking the following actions:

(1) *Tasking the National Science Foundation (NSF) to undertake a strategic planning effort for the EPSCoR program that specifically recognizes the heterogeneity of EPSCoR jurisdictions and the importance of allowing them to play to their unique strengths.* The current NSF grants program to EPSCoR jurisdictions (especially the Track 1 program), in my view, takes too much of a "one size fits all" approach. Although the word "experimental" is now gone from the EPSCoR definition, I believe Congress should encourage NSF to allow much greater flexibility in what EPSCoR states propose and use them as test beds for experimenting with new approaches to research, *e.g.,* engagements with industry, partnerships with indigenous peoples.

(2) *Provide waivers to EPSCoR jurisdictions of certain administrative compliance requirements that have little to no practical benefit but consume enormous amounts of researcher time.* Three separate surveys, conducted roughly 7 years apart over the past 20 years, show that, on average, university faculty funded by Federal research grants spend 42 percent to 44 percent of their time on

administrative activities unrelated to the research itself. This is an enormous waste of intellectual horsepower not to mention taxpayer funds. Many other studies show how these numbers can be reduced without sacrificing transparency and accountability. Consequently, *Congress should "run an experiment" with EPSCoR jurisdictions to demonstrate how greater efficiency and cost savings can be achieved, collect data on outcomes, and carefully evaluate the results.* The COVID pandemic clearly demonstrated that America's research enterprise can move with much greater speed and efficiency than most thought possible if certain regulations are streamlined or suspended—all without losing integrity or compromising quality or accountability. *Those lessons learned should be harvested and applied more broadly, and the EPSCoR program is the perfect place to begin with an experiment.*

Question 2. Last Congress, this Committee and President Trump signed the Secure and Trusted Communications Networks Act into law. Also known as "rip and replace," this legislation authorized funding for smaller providers to "rip" vulnerable equipment in their communications networks and replace it with secure alternatives. In December, Congress was also able to provide $1.9 billion to fund this legislation. It is for this reason—I believe—we need to reduce our reliance on foreign production, especially in critical systems, and encourage a more diverse supply chain. How can we encourage smaller companies, like rural Internet service providers, to incentivize the diversification of their supply chains over more expedient choices?

Answer. Thank you very much for supporting the TCNA. As former Director of OSTP, I am keenly aware of the extraordinary threats posed by malevolent actors in our communications systems and strongly believe in securing supply chains and enhancing domestic providers. With regard to smaller companies, especially those servicing rural areas, operating on very thin margins provides little capability for them to address the important problem you mention. Yet those very same areas are the ones typically left behind by bigger carriers for the same reason. *I believe a Federal grant program might work best, in which smaller and rural-provider companies could compete for funds, sharing some of the costs themselves.* In comparison to a pure Federal subsidy, a competition would require such companies to take a more entrepreneurial approach, putting skin in the game and perhaps teaming with other local providers to maximize capability while not compromising quality of service that rural communities rightly expect.

Additionally, agricultural extension offices at Land-grant institutions could play an important role here as the new Land-grant concept involves supporting not only agriculture, but also rural technological development. As you know, each Land-grant institution has extension offices in every county, and that connective tissue can be leveraged to build out from agricultural support to technology and other areas of economic development. Your staff may wish to speak with University of West Virginia President, Dr. Gordon Gee, who is an exceptional leader and may have additional thoughts about how Land-grants can assist in addressing your good question. In fact, *having Land-grants coordinate the funding I mentioned above, working with rural telecommunications providers, would be a powerful mechanism for leveraging the assets of public university investment in ensuring national security.*

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARIA CANTWELL TO MARIE LYNN MIRANDA, PH.D.

Question 1. In your testimony, you mentioned that iNDustry Labs at the University of Notre Dame works to link faculty, students, and R&D capabilities with companies in the region to enhance the local innovation ecosystem. Which elements of that program can be replicated at other universities?

Answer. INDustry Labs at the University of Notre Dame operates in a way that is similar to land grant universities' agricultural extension programs and the manufacturing extension programs (MEPs) mentioned during the hearing that are administered by the National Institute of Standards and Technology. The iNDustry Lab team works with regional partners to identify opportunities to apply modern strategies, advanced technologies, and business management processes, helping them to remain competitive and meet dynamically changing market needs.

As Notre Dame's mechanism for collaboration with local industry, iNDustry Labs has dedicated resources and streamlined processes to assist small-and medium-sized businesses unfamiliar with navigating the opportunities presented by an R1 research institution. Its goal is to lower the barriers to collaboration and benefit all parties.

At the heart of iNDustry Labs is an experienced staff that is savvy in both technology *and* business to serve as the interface with regional industry. These experts include "engineers in residence"—practitioners with strong regional ties and extensive industry experience who match business needs with university resources, including sophisticated labs and instrumentation as well as STEM students and faculty members. In doing so, they function as an innovation and transformation program for regional businesses.

The beauty of this model is that it helps modernize and grow regional businesses, creating employment in rural areas and small cities, while also providing university students and faculty with a laboratory in which to apply their knowledge and skills to real-world problems, strengthening our region and university. Connecting students with local industry partners also creates relationships that can lead to postgraduate employment—a win for both students and regions that compete to attract the talented workforce they need to modernize. INDustry Labs' broader scope—extending beyond the manufacturing sector—distinguishes it from the MEP model. By design, iNDustry Labs programs complement, and do not compete with or duplicate, programs run by Purdue MEP.

Other colleges and universities can apply and adopt every aspect of this program to help identify and address regional needs. What would be required is a grants program funded through federal, state, and county partnerships, similar to the mechanisms that currently fund agricultural extension programs—or possibly by expanding the scope of the MEP charter to increase their flexibility to both serve regionally targeted industries beyond the manufacturing sector and draw more substantively from the resources of regional universities. Ideally, any of these partnerships would also involve (as Notre Dame's program does) community colleges so that they can offer a full range of educational and workforce development programs.

STEM Diversity. In your testimony, you spoke to the value of broadening participation in STEM fields and the importance of both the Graduate Research Fellowship Program and the Research Experiences for Undergraduates program at universities across the Nation.

Question 2. What can the Federal government do to increase the total number of people going into STEM fields?

Answer. First, it is important not to view the many careers in STEMM fields as a single pipeline, but instead as a variety of pathways that lead to many different careers within a STEMM-enabled workforce. The diverse workforce required to ensure our security and global competitiveness includes those working in STEMM fields ranging from basic discovery science to design, development, and deployment of new technologies such as precision agriculture, medical diagnostics, and tele-education, to advanced manufacturing, for example.

What these pathways have in common is a fundamental understanding and ability to apply basic science and mathematics concepts that most students should gain in K–12 education programs. From this foundation, pathways diverge. Some students will pursue bachelor, masters or Ph.D.s, discovering, designing, and developing our future. Others may pursue an associate degree, apprenticeships, or training in skilled trade, serving as the users, deployers, and managers of advanced technology applications. Some will identify these career paths early in their academic training, others only after they have had real-world experience to help them discover a fulfilling career goal.

We need all of these people and career pathways, and we should encourage all students to pursue the level and field that best suits them. We should also guard against the tyranny of low expectations. Instead, we should enable and encourage all students to pursue their highest aspirations.

To do so, we need to create funding and support mechanisms that encourage research institutions to collaborate with middle schools and high schools *at scale,* including professional development of middle and high school science teachers who deliver STEMM curricula and support for science-focused after school programs and summer programs at universities. We need these students to gain meaningful on-campus STEMM experiences. We should separately fund a full-scale analysis of the effectiveness of different approaches.

In parallel, we should fund the development and maintenance of networks designed to provide mentorship, research rotations, internships, shadowing programs, support systems, and career advancement in STEMM fields at all levels, especially as they are relevant to gender, racial, ethnic, income, and geographic diversity.

For those pursuing higher-level STEMM degrees, we should seed-fund the development of wrap-around services for first-generation students and those from low resource backgrounds to ensure they can prosper in STEMM fields. The Notre Dame Scholars program provides a good model for such efforts, offering smaller classes,

STEMM enrichment activities, and programs that teach these students how to study and prepare more effectively to succeed in rigorous STEMM curricula. Separately we should fund a full-scale analysis to assess effectiveness of different interventions and different elements of interventions, preferably as randomized controlled trials.

At the highest educational levels, we should dramatically expand funding for NSF Graduate Research Fellowships (GRFs) and Research Experiences for Undergraduates (REUs), programs that are incredibly effective at attracting and retaining young scholars in STEMM. We should also craft and fund similar programs for high school students and masters-level students, allowing them to gain on-campus experiences at universities to show them what is possible for them via the pursuit of higher-level education.

Question 3. Are there steps the Federal government should take to ensure universities have capacity to absorb additional STEM students?

Answer. Significantly increasing the number and diversity of university students who pursue STEMM education will require a consequent increase in the number of faculty members required to teach them. Moreover, as we have learned at Notre Dame, encouraging first-generation and underrepresented minority students—who are very capable yet often are not as well prepared coming out of high school as other students—to persist in their chosen majors requires smaller class sizes and additional enrichment efforts, including exposure to research and learning skills development. Again, these students are very capable—but once their grades (and esteem) meet the reality of college-level chemistry and calculus, they all-too-frequently change majors, costing our Nation talented STEMM graduates.

The Federal government could address this issue by:

(1) Providing 3–5 year grants to universities to develop the wrap-around services that students from low resource backgrounds require to achieve high STEMM persistence rates.

(2) Supporting serious evaluations of what works and what does not work to develop the best practice evidence basis for dissemination across higher education.

(3) Helping fund additional STEMM faculty members through a 5-year program in which the government pays a portion of a new STEMM faculty member's salary. This would create the "ramp" to follow-on endowment or other faculty funding mechanisms that could include industry partnerships or other public-private funding. The same program should be available to community colleges. NSF funded a similar effort in 2018 to stimulate advances in quantum computing.

Question 4. What are the best metrics to use when evaluating interventions aimed at improving STEM diversity?

Answer. The more specific the metrics, the better. We should seek to measure intervention and program effectiveness by their impact on the following:

- Number and demographics of those who intend/declare STEMM majors
- Year-by-year persistence in STEMM both in total and disaggregated by demographics
- Year-by-year progress toward a STEMM degree as measured by courses taken both in total and disaggregated by demographics
- Number and percentage of students who engage in STEMM research both in total and disaggregated by demographics
- Number and percentage of students who engage in a STEMM-related summer experience both in total and disaggregated by demographics
- Number and percentage of students who graduate with a STEMM degree both in total and disaggregated by demographics
- Number and percentage of students intending to pursue STEMM careers both in total and disaggregated by demographics
- Year-by-year evaluation of student satisfaction with STEMM courses, STEMM majors, research experiences, advising, internship opportunities, and supportiveness of the environment for diverse students

At the macro level, we should also measure the number and characterize the nature of the STEMM jobs available nationally, regionally, and locally, so that we can tailor programs to meet demand.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. AMY KLOBUCHAR TO MARIE LYNN MIRANDA, PH.D.

Diversity in STEM. Ensuring diversity in STEM education is a top priority for me. One study found that women's authorship of scientific journal papers declined 23 percent during the pandemic.

Question 1. Can you speak to the trends you are seeing on your college campus of women and minorities' engagement in STEM related research and studies?

Answer. Pandemic Impacts on Women: Evidence from a grant and teaching relief program Notre Dame established to assist faculty whose research and creative endeavors were disrupted by the pandemic suggests that the pandemic negatively affected women faculty members more than men. To be clear, we were not trying to assess gender-specific pandemic impacts. However, women, who comprise 33 percent of our faculty, represented 44 percent of those who applied for assistance grants and 57 percent of applications for relief from teaching courses.

Women Pursuing STEMM Education: The University of Notre Dame is a private, residential Catholic research university with about 8,500 undergraduate students and 3,700 graduate and professional students. Roughly 10 percent of our undergraduates attend medical schools after graduation. As such, we have long enjoyed an above average percentage of women pursuing science, engineering, and mathematics degrees compared with large public research universities. In recent years, we also have seen increased female enrollment in mathematics-heavy programs such as neuro-biology, psychology, and economics, a field long dominated by men.

The percentage of women undergraduates in our College of Engineering (33 percent) is above the national average (22.5 percent). However, this percentage has not increased during the past five years, despite national data indicating that women increasingly graduate high school more "STEMM-ready" for college than men, and we are working to change this.

During the past five years, we have seen a 40 percent increase in the number of women declaring majors in our College of Science. Women currently comprise about 60 percent of our science majors even as the overall number of students in our College of Science has increased by roughly 43 percent. The number and percentage of women undergraduate students receiving summer research fellowships in science has remained roughly constant during this same time.

Underrepresented Minorities Pursuing STEMM Education: In recent years, an increasing number of underrepresented minorities have enrolled at Notre Dame intending to pursue a STEMM degree. However, many of these very capable students have not had the benefit of advanced high school science, engineering, and mathematics enrichment courses and programs that their white counterparts have experienced. As a result, the confidence and self-esteem of these first-generation and underrepresented minority students suffer when they encounter the rigors of college-level science and engineering curricula, and many choose to transfer to other academic degree programs.

To address this concern, in 2018 Notre Dame created a STEMM Scholars Program to support, encourage, and mentor first-year students pursuing STEMM degrees who may not be as well-prepared as other students. We assign them to carefully designed cohorts with smaller classes and provide them with enrichment programs that feature selected faculty members, who are often underrepresented minorities or were first-generation students themselves. Through multiple years of data collection and analyses, we know that these students can succeed in STEMM fields and that they bring important diversity to our university community. Data collected to assess the effectiveness of this program indicate that students taking part in the program are more likely to be "on track" toward STEMM degree completion. In the first cohort, 80 percent of program participants were taking appropriate courses in sequence compared to 69 percent of similar students in a control group. In the second cohort, 96 percent of program participants were on track compared with 90 percent of the control group. Moreover, 86 percent of program participants have a grade point average above 3.0, compared with 69 percent of students in the control group. Though the results of this program are encouraging, this effort suffered a setback during the pandemic when restrictions limited in-person student engagement with faculty members and peers. Though we have yet to conduct a detailed analysis of the effects, we have seen an increase in the number of first-year women and minority students who transferred from STEMM to other degree programs during 2021. We will redouble our efforts to reverse this decline starting in the fall of 2021.

Question 2. In your view, what more can be done to help increase women and minorities pursuing careers in STEM?

Answer. The importance of women and underrepresented minority role models in STEMM fields cannot be overstated. We need to help young women and minority

students see others who look like themselves leading and succeeding in STEMM careers so that they believe it is possible for them to succeed as well.

It also is important not to view the many careers in STEMM fields as a single "pipeline," but rather as a variety of pathways that lead to many different STEMM careers. What these pathways have in common is a fundamental understanding and ability to apply basic science and mathematics concepts that students should begin gaining in K–12 education programs.

From this foundation, pathways diverge. Some students will pursue a bachelor's, master's, or Ph.D., discovering, designing, and developing our future. Others may pursue an associate's degree, apprenticeships, or training in a skilled trade, serving as the users, deployers, and managers of advanced technology applications. Some identify these career paths early in their academic training, others only after they have had real-world experience to help them discover a fulfilling career goal. We must guard against the tyranny of low expectations. Instead, we should enable and encourage all students to pursue their highest aspirations. In my written testimony, I highlighted the need to fund and support mechanisms that encourage research institutions to collaborate with middle schools and high schools at scale, including professional development of middle and high school science teachers who deliver STEMM curricula and support for science-focused after-school programs and summer programs at universities. We need these students to gain meaningful on-campus STEMM experiences. We should separately fund a full-scale analysis of the effectiveness of different approaches. In parallel, we should fund the development and maintenance of networks designed to provide mentorship, research rotations, internships, shadowing programs, support systems, and career advancement in STEMM fields at all levels, especially as they are relevant to gender, racial, ethnic, income, and geographic diversity.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. SHELLEY MOORE CAPITO TO MARIE LYNN MIRANDA, PH.D.

Question 1. Last Congress, I join my colleague Senator Rosen in introducing the Building Blocks of STEM Act. Among other things, this legislation modified NSF's Discovery Research PreK–12 program to more equitably distribute funding to elementary and prekindergarten education. Last Congress, we were able to get this legislation passed and signed into law. I was proud to work with Senator Rosen on this bipartisan legislation to encourage more young women to explore STEM fields. How important is it to instill creativity and curiosity in younger students—and especially young girls?

Answer. I commend Senator Capito, Senator Rosen, and their colleagues for their bipartisan efforts to pass the Building Blocks of STEM Act during the 116th Congress. Curiosity, creativity, and problem-solving skills are all essential building blocks for anyone pursuing STEMM (science, technology, engineering, math, and medicine) careers, and this is especially true for Pre-K girls and underrepresented minority students.

Just as we know from literacy studies that reading interventions for kindergarten students result, on average, in a 15 percent higher reading score in the 3rd grade [1], so too do we know that mathematics interventions targeted to 3-to-5-year-olds, such as *Rightstart, Pre-K Mathematics,* and *Building Blocks,* help students develop numerical and spatial/geometric reasoning. Large scale studies of these curricula have shown that low-income students participating in these programs out-performed not only a control group of similar peers, but also students from middle-class backgrounds embedded in a mathematics enriched environment. Other non-achievement-based outcomes also are shaped in critical ways at this age level [2].

In one study, children ages 3 to 7, working with a curriculum using engineering storybooks more strongly identified themselves as potential engineers following the experience [3]. Promising early childhood interventions, therefore, address both cognitive development and the development of STEMM identities.

Importantly, as we look at representation across the STEMM disciplines, it is necessary to take a nuanced approach to analyzing the conditions that are fertile for the flourishing of women in STEMM pathways. While data reported by the National

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[1] Wanzek, J., Stevens, E. A., Williams, K. J., Scammacca, N., Vaughn, S., & Sargent, K. (2018). Current evidence on the effects of intensive early reading interventions. *Journal of Learning Disabilities, 51*(6), 612–624.

[2] Clement, D., & Sarama, J. (2011). Early childhood mathematics intervention. *Science,* 333(6045), 968–970.

[3] Pantoya, M. L., Aguirre-Munoz, Z., & Hunt, E. M. (2015). Developing an engineering identity in early childhood. *American Journal of Engineering Education, 6*(2), 61–68.

Science Foundation indicate that women now earn the majority of degrees in certain STEMM fields (*e.g.,* at least 60 percent of bachelors and master's degrees, and more than half of doctoral degrees in biological sciences), women remain persistently underrepresented in a number of disciplines, including computer science, engineering, and mathematics, and statistics [4].

Therefore, it is important to identify ways in which young people can be exposed to a range of experiences in underrepresented sectors of STEMM at an early age, so that we foster their interest, help them construct a positive identity toward these disciplines, and reduce the potential for them to form negative stereotypes.

There is growing evidence that young children, even in pre-school, develop persistent and individualized interest in activities and topics that impact subsequent learning and development [5]. Early opportunities to engage in meaningful STEMM, such as the types of experiences in pre-kindergarten and the elementary grades that you advocated for in your legislation, can have powerful and formative impacts on young students that can prime them for the ongoing development of creativity and curiosity during future years.

At Notre Dame, we recognize the importance of early childhood interventions and the roles they play in the flourishing of children. For example, the Head Start on Engineering project, co-directed by Dr. Gina Navoa Svarovsky at Notre Dame's Center for STEM Education, looks at how 4-and 5-year-old children and their families engage with appropriate engineering activities as a way to build early engineering interest and understanding.

Findings from Dr. Svarovsky's work suggest that an early interest in STEMM education for young children is not only an individual phenomenon, but also one that occurs at the family level—thereby pointing to new avenues and pathways that may lead to increased curiosity and creativity, and ultimately, more students pursuing STEMM careers [6].

In sum, it is the combination of interest and identity—formed by curiosity and creativity at a young age—that lead children to pursue STEMM education and careers. It starts with children asking questions, seeking answers, and constructing meaning about the world around them, all practices that are foundational to science, mathematics, engineering, and computer science.

Moreover, we see evidence from large data sets of high school students that these motivational variables, interest and identity, are the strongest predictors of an individual's desire to pursue a STEMM career. This is particularly important for underrepresented populations in STEMM, like women and minorities [7].

Response to Written Question Submitted by Hon. Maria Cantwell to Dr. David Shaw

Question. I recently visited the Rose-Hulman Institute of Technology in Indiana, which has adopted a unique model of partnering with local industry to give students real world engineering and entrepreneurship experience. You talked about the importance of entrepreneurship in your testimony. What can we learn about teaching engineering and entrepreneurship from your experience at Mississippi State?

Answer. Mississippi State University's Entrepreneurship Center (E-Center) is an award-winning program that is led by the College of Business but with student and faculty participation from across the university. The E-Center is responsible for a number of successful student startup companies. Its primary location is on the MSU campus, but has opened up an Idea Shop in downtown Starkville as well as a Maker Space downtown. The E-Center participates in the National Science Foundation's I-Corps program, which provides training to learn the fundamentals of building business models, along with travel funds, and access to follow-on grants from the NSF in excess of $1M. The E-Center has created a comprehensive, co-curricular program for MSU's students and faculty who are interested in starting a successful, investor-backed company called VentureCatalyst.

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[4] *https://ncses.nsf.gov/pubs/nsf21321/report/field-of-degree-women#overview*

[5] Ainley, M., & Ainley, J. (2015). Early science learning experiences: Triggered and maintained interest. In Renninger K. A., Nieswandt M., Hidi S. (Eds.), *Interest in mathematics and science learning* (pp. 17–32). American Educational Research Association.

[6] Pattison, S., Svarovsky, G., Ramos-Montañez, S., Gontan, I., Weiss, S., Núñez, V., Corrie, P., Smith, C., & Benne, M. (2020). Understanding early childhood engineering interest development as a family-level systems phenomenon: Findings from the Head Start on Engineering Project. *Journal of Pre-College Engineering Education Research* (J–PEER), 10(1), 6.

[7] Andersen, L., & Ward, T. (2014). Expectancy-value models for the STEM persistence plans of ninth-grade, high-ability students: A comparison between black, Hispanic, and white students. *Science Education, 98*(2), 216–242.

What continually amazes me is the creativity of our students when given the opportunity to collaborate across disciplines, generating ideas that engender enthusiasm from our alumni supporters as well as the venture capital community. Entrepreneurship can happen anywhere in the U.S. where innovation is fostered and encouraged.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. SHELLEY MOORE CAPITO TO DR. DAVID SHAW

Question 1. The Established Program to Stimulate Competitive Research (EPSCoR) Program is a critically important program for small, rural states like mine. EPSCoR helps states like mine build research capacity. Even during the COVID-pandemic, funding through EPSCoR has allowed West Virginia to continue with various research projects in areas ranging from advanced materials to robotics. How can Congress better leverage the potential in EPSCoR jurisdictions?

Answer. The EPSCoR program does in fact play a vital role in building research capacity in qualifying jurisdictions. EPSCoR states are blessed with highly competent researchers, and we simply need to be given the opportunity to compete on a level playing field in order to maximize the scientific benefits derived from these investments. Currently there is discussion about 20 percent provision to the EPSCoR program; this would be a substantial and appropriate level of funding to ensure the geographic diversity that all recognize is needed.

It is exciting to see some of the ideas put forth in the Endless Frontier Act language that recognizes the need to give students, regardless of geography, the opportunity to participate in cutting edge scientific endeavors. However, the language does not go far enough in ensuring that the same few major research institutions do not yet again receive most of this funding. That is not to say that high-quality, peer-reviewed science should not be funded. Rather, specifying that a substantial portion of the funds be set aside for competition among institutions who are not in the top 1 percent of NSF funding would accomplish this effectively, ensuring geographic diversity and maximizing impact on our Nation.

In addition, the concept of additional funding for technology development research, with a portion set aside for the EPSCoR program, is very encouraging. Ensuring additional funding targeted for EPSCoR jurisdictions will provide tremendous benefit to our states. This program will, in many instances, dramatically benefit EPSCoR states, since our institutions often are very focused on applied science and technology development for our states, since this is a often a pressing need.

Question 2. In 2018, my home state of West Virginia received $280 million out of the total $125 billion Federal investment in research and development. Dr. Shaw, I agree with your sentiments that Congress should address the disparity between states. How can Congress ensure a more balanced geographic distribution of Federal research funding?

Answer. Several suggestions have been given above, all of which would greatly aid in a more equitable geographic distribution of NSF funding. In addition, Regional Hubs, Manufacturing USA consortia, and Innovation Centers all contain language that gives a nod to the involvement of universities in EPSCoR jurisdictions, and to geographic diversity. However, this simply is not enough. In many past instances, the same few universities that receive the vast majority of funds simply add an institution in an EPSCoR jurisdiction, without providing significant funding or leadership roles. To balance this, NSF should be required to have a substantial number of these various consortia and centers to be led by institutions in EPSCoR jurisdictions.

RESPONSE TO WRITTEN QUESTIONS SUBMITTED BY HON. MARIA CANTWELL TO WILLIAM B. BONVILLIAN

Question 1. Investing in cybersecurity workforce development on a broad scale is a priority for me and for the Washington State economy. During the New Deal era, Washington workers benefitted from public works programs that included job training. How can today's Federal government leverage existing programs and, as appropriate, establish new programs to rapidly and substantially grow the cybersecurity workforce?

Answer. I noted in my testimony to the Committee on April 14th the important role played by NSF"s Advanced Technological Education (ATE) Program. This program is already playing a significant role in the massive task of training a skilled cybersecurity workforce, and could be further expanded. As the Committee knows,

the ATE program provides grants for the development of innovative workforce education efforts for educated highly skilled technicians for industries important to the future of our economy. Cybersecurity is one of those fields. Because they are nation's key mechanism for skilled workforce education, educators at 2-year institutions—community and technical colleges—are the major recipients of ATE funding, and the program encourages consortia led by these schools that include industry and universities. The 2-year schools offer career pathways with certificates and degrees that can lead to jobs in key technical fields. ATE funds both Centers of Excellence in advanced fields, as well as smaller more focused project grants. In cybersecurity education, ATE has funded five Centers, and each in turn, helps create cybersecurity programs at numerous participating schools (see, Mariacopa CC and NSF, ATE Centers for Cybersecurity Education, 2016 (updated)). To cite one example, the center in Daytona, Florida developed curricula and five fully accessible cybersecurity courses for 2-year institutions with video and scenarios that promote "real life" technical skills and technical report-writing, it developed online courses for cybersecurity faculty training at 58 institutions in 25 states, and it held and enabled high school-level cyber camps to encourage participation in this new field. The other four centers have launched comparable innovative programs.

In my view, further expansion of ATE programs, and ensuring close connections and linked programs between ATE and the new Technology Directorate proposed in the Endless Frontier Act, as well as the proposed university tech development centers and the proposed regional innovation centers, could further improve technical education in critical new technology areas. A workforce education component should be built into their roles.

In addition, a new Advanced Manufacturing Institute (CyManII—*https://cymanii.org/about-us/*) for cybersecurity in manufacturing has recently been established through DOE. Headquartered in Texas, its 59 initial members include major companies and universities. Workforce education along with technology development is a specific mission for Institutes. While this institute is starting up, other Institutes have created workforce education programs that:

- Develop competencies and "Knowledge, Skill and Abilities" (KSA) in the Institute's technology area that can be used by employers and education institutions.
- Develop demonstration and training centers for workforces to train on new equipment and processes—and for student training programs.
- Engage in training efforts with regional industry, community colleges and high schools.
- Map skill demands and develop skill roadmaps in their technology areas and tie these to their technology development roadmaps
- Track evidence of trends in workforce skill development in the technology area affected by the Institute's programs.
- Develop online education in their technology area (and in some cases, computer gaming and VR/AR for hands on learning), which is key to scaling.
- Certify education programs in their technology area and develop, as needed, with their industry members, new industry-approved credentials, so educators and workers know what to train for.

Thus, the Manufacturing Institutes are developing an important workforce education role in advanced technologies, as well, and merit further support, as the Endless Frontier Act proposes.

Question 2. Innovation requires an ecosystem and that ecosystem can't work without trained workers. You have previously reviewed the Manufacturing USA program, which is experimenting with new ways to train the workforce, and work at MIT, a leader in online education. Given your experience with those efforts, what elements and best practices are necessary to build a workforce that's ready to lead the way on new technologies, particularly to train individuals who typically do not have access to other educational programs?

Answer. Drawing from the specific findings from a benchmarking study for the State of Massachusetts on best practices for advanced manufacturing education (see, MIT Open Learning, MassBridge: Advanced Manufacturing Education Workforce Education Program, 44–46 (April 2021)), which I prepared with MIT colleagues, as well as from a new book (see, *Workforce Education, A New Roadmap,* 207–235 (2021), with Sanjay Sarma), below are a series of recommendations that exemplify some of the best practices in workforce education, which may be useful to the committee:

1. *Break down the work/learn barrier.* Employers and educational institutions need collaborate closely on content development and content delivery for work-

force education. Strong programs offer a work component for students, which can range from internships to formal apprenticeships, along with academic instruction.

2. *Employers should collaborate with each other.* Stand-alone programs where individual firms provide their own training tend to be inefficient; it is better if groups of firms share the costs and risks of workforce education. Better still is where larger firms and their regional suppliers can band together since efficient workforce education requires adoption across supply chains. These employers in turn need to work with area educational institutions and state education and labor programs, in offering programs and in designing and updating curricula to meet workplace needs. Education institutions can help manage the infrastructure for these consortia, shouldering much of the administrative burden.
3. *Reach new entrant, underemployed, and incumbent workers.* Educational institutions need to adapt their program mix to reach all of these participants. If an institution—a community college and/or employer consortia—can reach all three groups, the elements become reinforcing. A program for incumbent workers requires close contact with employers, which helps keep programs for all students current with industry needs. Community college or employer programs can also reach high school students, helping to break down the work/learn barrier and link high school students to college opportunities.
4. *Embrace certificates and shorter-term programs.* In addition to offering only full degrees earned in a fixed period of time, educational institutions should be encouraged to provide shorter-term certificates, based on acquired competencies, that be stacked and can accumulate toward degrees. Certificate programs can help workforce education fit students with limited time availability and employers with particular skill requirements. Degrees that take two years or more will still be needed but can be based on a series of related, stackable credentials. This, in turn, can enable short programs that help workers get to required skills and employment earlier, plus there is a pathway toward additional skills or a degree, as desired.
5. *Embed an industry-recognized credential into education institutions' certificates.* Academic credentials are not enough. Many employers increasingly want the assurance of skill knowledge that an industry-approved and accepted credential provides. It creates an additional and parallel pathway to help students toward employment. It also ensures that academic programs are relevant to actual industry needs.
6. *Ensure access to advanced manufacturing equipment.* Employers want students who have actual experience with the latest production technologies. Because of the cost of equipment, there is a significant challenge in getting students hands-on learning, particularly for advanced equipment. One approach is for a state to create regional technology centers shared by consortia of community colleges, high schools, and employers. In addition to providing efficient student access to equipment, providing companies access can help them test and experiment with new equipment, evaluating how it can improve their production process, and assist in training for their workers.
7. *Apply new education technologies that can scale.* We are not educating adequate numbers of workers with skills required for the new technologies, so online education, which can scale rapidly, will be a key step. Education offerings with new content can be blended, combining face-to-face with online education, which can help expand their reach to much higher numbers of students. Hands-on learning remains critical, but actual equipment can be supplemented with advanced technologies, including computer gaming-based courses and Virtual Reality and Augmented Reality (VR/AR) technologies.
8. *Create cross-state industry and community college coordination mechanisms.* A state-wide organization for employers in key industrial sectors, as well as working consortia of the state's community colleges, that work together to implement workforce education programs for new technologies, is needed. This ongoing industry and school collaboration is key to developing new programs and keeping them current.

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