REIMAGINING OUR INNOVATION FUTURE

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

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C O N T E N T S

April 15, 2021

REIMAGINING OUR INNOVATION FUTURE

THURSDAY, APRIL 15, 2021

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

The Committee met, pursuant to notice, at 10:02 a.m., via Zoom, Hon. Eddie Bernice Johnson [Chairwoman of the Committee] presiding.

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

"Reimagining Our Innovation Future"

Thursday, April 15, 2021
10:00 a.m. – 12:00 p.m.
Zoom

Purpose

The purpose of this hearing is to examine the current outlook for U.S. leadership in science and technology and discuss how new investments and new, inclusive models of partnership in science and technology can be leveraged to ensure continued leadership and address economic, security, environmental, public health, and other societal challenges from the local to the global level.

Witnesses

- **Mr. Norm Augustine**
- **Dr. Frances H. Arnold**, Linus Pauling Professor of Chemical Engineering, Bioengineering and Biochemistry, California Institute of Technology
- **The Honorable Ernest J. Moniz**, President and Chief Executive Officer, Energy Futures Initiative, and Former Secretary, U.S. Department of Energy
- **Dr. Farnam Jahanian**, President, Carnegie Mellon University

Overarching Questions

- What is the state of U.S. leadership in science and technology, and the outlook for continued leadership, particularly in areas of science and technology that will help drive economic competitiveness and national security in the coming decade? Why is it important for the U.S. to maintain leading capabilities in both fundamental research and technology development?
- How can Federal science agencies more effectively partner with each other, universities, companies, foundations, local and state governments, and diverse local and national stakeholders, to advance scientific and technological solutions for local, national, and global challenges? How do we incorporate an inclusive approach to the partnerships to ensure that we are tapping all of the nation's brainpower?
- What investments in research, development, and the STEM workforce are required to ensure that competitiveness and solutions-driven research are mutually reinforcing and not competing goals?
- How do we balance research collaboration and the security of Federally funded research?

U.S. RESEARCH & INNOVATION LANDSCAPE

Overall Spending

According to the National Center for Science and Engineering Statistics at the National Science Foundation (NSF), the total U.S. investment in R&D by all sectors was $656 billion in 2019. The business sector has accounted for most of the growth in total U.S. R&D over the last decade. In 2009, businesses invested $247 billion in R&D, compared to $126 billion by the Federal government. In 2019, these numbers rose to $464 billion and $139 billion, respectively, which means the business sector now accounts for 70 percent of all U.S. R&D. The remaining $53 billion comes from states, foundations, non-profit organizations, and universities' institutional funds.

Federal R&D Investment

Federal support for R&D as a percentage of the nondefense discretionary budget has held mostly steady at 10 percent since 2000, but the total size of the nondefense discretionary budget decreased under the 2011 budget deal known as "sequestration." In the years 2012-2017, Federal investments in R&D decreased in absolute numbers, surpassing the 2009 level only in 2018. In constant dollars, the R&D buying power at several Federal agencies is still lower than it was prior to sequestration.

The Federal government invests broadly across the R&D spectrum. The majority of the non-defense R&D budget, which totaled approximately $91 billion in FY 2020 (not including emergency funding for COVID), is dedicated to basic and applied research. Approximately 29 percent of all Federal R&D is intramural, i.e. performed by the Federal agency itself, 16 percent is performed by Federally Funded Research and Development Centers (FFRDCs), 20 percent is performed by business, 28 percent is performed by universities, and 6 percent is performed by other non-profit research organizations.

Federally Funded Research and Development Centers

FFRDCs, which includes the Department of Energy National Laboratories, play an important role in our R&D enterprise. In particular, they play a unique role in supporting large-scale, long-term R&D, including through the construction of major user facilities in key technology areas, including computing and biotechnology. Because they are distributed across the country, including in states and regions that are generally not among the highest in research and innovation capacity, they also serve an important role in local economic development and in providing STEM education and research experiences to students who might otherwise not have such access.

University R&D Investment

The United States has long been home to many of the world's leading research institutions. In 2019, U.S. universities performed a total of $83.7 billion in R&D from all sources, including $39.5 billion in Federally funded R&D. The share of academic R&D funded by Federal agencies declined from 57 percent in 2009 to 50 percent in 2019. Other sources of funding include institutional funds, industry, and foundations. In 2019, institutional funds supported 27.7 percent of university research. University research advances foundational knowledge in science and technology. Universities are also the source of thousands of spin-off companies that contribute to regional economic development and job creation. Such spin-offs are primarily clustered in geographic proximity to the university.

Corporate R&D Investment

Since 2000, the rise in U.S. investments in R&D has largely been driven by increased investments in the private sector, which prioritizes short-term applied research and experimental development focused on

improving specific products and processes. Decades ago, tech companies invested significantly more in higher-risk fundamental research. By 2017, businesses funded nearly 30 percent of all fundamental research. However, the U.S. pharmaceutical industry alone accounts for more than 50 percent of the increase in corporate sponsored fundamental research since the mid-2000's. Similarly, philanthropic support for research has been on the rise, but it has been overwhelmingly focused on biomedical research. While some fundamental research performed by companies is published in the open literature, much of it remains proprietary.

Public-Private Partnerships

There are many partnerships between the government (including national labs), universities, and the private sector, and the Committee on Science, Space, and Technology often explores the nature of those partnership models - what works, what can be expanded, and what new models may be viable. Such partnerships require a sustained commitment by all parties and new ways of partnering as new challenges and opportunities arise. They also require new thinking as to who the partners must include. There is increasing focus on bringing to the table non-traditional partners, including local governments and community organizations, civil society organizations, labor organizations, and others who might be users of, or might be affected by, the research being carried out.

CHALLENGES TO THE INNOVATION ENTERPRISE

Stagnant or Decreasing Funding for Fundamental Research

The U.S. R&D enterprise is under pressure, especially the fundamental research that creates the foundation for new innovations and trains the next generation of STEM talent. University researchers spend a significant portion of their time applying for grants from programs with proposal success rates as low as 10 percent. Because of the low success rates, agencies and peer review panels are taking fewer risks in the grants they do fund. Many of the most talented students who otherwise might have made significant contributions to U.S. leadership in S&T see little to no future in academic research and pursue careers in the private sector, or head abroad to countries in which research funding is more readily available.

International Competition

The U.S. innovation enterprise currently faces unprecedented global competition and action is needed to maintain our competitive edge. Innovation has been a key driver of economic growth in the United States and other nations have raced to replicate our successful models for innovation. China alone has accounted for almost one-third of total global growth between 2000 and 2017, compared to 20 percent for the U.S and 17 percent for the European Union. In that time frame, the U.S. has shifted from making up 37 percent of global R&D share to 25.5 percent. China's investments likely exceeded those of the United States in 2019. As a share of GDP, the U.S. is close to dropping out of the top 10 in R&D expenditures.

If the U.S. is to maintain its competitive edge in science and technology, the nation must reinvest in our innovation enterprise to expand capacity, participation, and collaboration and allow for greater risk-taking. This is a particularly urgent issue for the U.S. in areas such as artificial intelligence, quantum computing, biotech, and other fields that will serve as the major platform technologies for innovation and competitive advantage, and lead to unprecedented national security challenges in the 21st century.

Also relevant to international competition is our ability to attract top talent from around the world. Temporary visa holders accounted for one-third of all STEM doctoral degrees awarded by U.S. universities in 2017, and half or more of all doctoral degrees awarded in engineering, mathematics, and computer sciences. The United States has long benefited from attracting the best talent from around the world. Thirty-five percent of all U.S. Nobel laureates have been foreign-born scientists since the Nobel Prize was first established in the early 1900s and 44 percent of the companies in the Fortune 500 were founded by immigrant entrepreneurs or their children. However, increasingly, foreign students are either choosing to study outside of the U.S. (the EU and Australia are popular destinations) or returning to their home countries after receiving their degrees in the United States.

As the Committee has heard from many expert witnesses, it is not an either-or question for universities. They want to attract the best global talent and recruit more U.S. citizens graduating with bachelor's degrees in science and engineering to pursue masters and doctoral level studies. However, in many fields, especially in information technology fields, U.S. students can earn good salaries straight out of college and are forgoing advanced degrees. Other challenges to the domestic STEM pipeline are discussed below.

Lack of Diversity in the STEM Enterprise

In 2017, the majority of scientists and engineers – all individuals trained or employed in STEM – employed in STEM occupations were employed in the business sector (64 percent), followed by education (13 percent) and government (11.6 percent). The skilled technical workforce – those who use S&E expertise in their jobs but do not have bachelor's degrees – account for a substantial component of the U.S. STEM workforce. The STEM workforce is aging. The median age of scientists and engineers in the labor force was 43 years in 2015, compared to 41 years in 1995.

In 2017, women with STEM degrees constituted 47.7 percent of employed individuals across all occupations, but only 29 percent of those in STEM occupations. There is significant variation across fields. Women are represented in relatively high proportions in social sciences (59 percent) and life sciences (48 percent) and relatively low proportions in engineering (15.5 percent), physical sciences (29 percent), and computer and information sciences (25.5 percent), the single largest and fastest growing STEM occupation. In 2017, underrepresented minorities accounted for 13.7 percent of all STEM degree holders working in STEM occupations and 13.6 percent of STEM degree holders employed in computing jobs. There is also a lack of regional diversity in our STEM workforce and research capacity. The 60,000,000 individuals living in rural areas in the United States are significantly underrepresented in STEM.

Institutional participation in the Federal research enterprise is also a factor in diversity. While there are 645 accredited U.S. institutions that award graduate degrees in science and engineering, the top 100 institutions perform 80 percent of all Federally funded research. None of the top 100 institutions is a Historically Black College and University (HBCU). Only seven are high Hispanic enrollment institutions. While some are in rural areas, they are heavily concentrated in urban and coastal regions. The top 30 institutions in terms of R&D expenditures accounted for 42 percent of the total spent on R&D (all funding sources) within the higher education sector in FY 2019. Those 30 institutions, while an essential part of our innovation enterprise, accounted for only 13 percent of the science and engineering bachelor's degrees awarded in 2018.

Studies on innovation have clearly demonstrated the benefits of diverse perspectives to innovation capacity and competitiveness.[1] Diverse perspectives and experiences are also required to maximize the benefits of technology and innovation for all Americans and minimize the risks. The ethical and societal risks of artificial intelligence systems, discussed at length in a 2019 Committee hearing, is just one example.[2]

If the United States does not increase and diversify participation in STEM, and particularly in fields such as computer and information science, we will continue to lose our competitive advantage. Our national security enterprise, which is competing with companies for the same talent, only hires U.S. citizens. The shortfall in domestic STEM talent is not just a competitive disadvantage, it is a significant national security risk.

COVID's Impact on Innovation

As discussed in a February 2021 hearing before the Committee, in 2020 and 2021, many of the existing demographic disparities highlighted above have been further deepened and exacerbated by the ongoing COVID-19 pandemic. In addition, across many fields, months of research time was lost. Even now, due to ongoing social distancing requirements, laboratories and facilities are not back up to full capacity. While some funding was provided to research agencies in the *CARES Act*[3] and the *American Rescue Plan Act of 2021*[4], it falls far short of the need. Last month, the Committee favorably reported H.R. 144, the *Supporting Early-Career Researcher Act*[5] and continues to push for passage of H.R. 869, the *RISE Act of 2021*[6] to get the U.S. research enterprise up and running and prevent a catastrophic loss of U.S. STEM talent.

Research Security

Concerns about threats to research security have increased in recent years. Such threats primarily arise from the failure of researchers applying for federal funding to disclose foreign affiliations, commitments, and sources of funding that may present a conflict of interest. Foreign talent recruitment programs, in particular, have been found to incentivize or coerce participants to acquire "through illicit as well as licit means, proprietary technology or software, unpublished data and methods, and intellectual property to further the military modernization goals and/or economic goals of a foreign government."[7] While data regarding the full scale and scope of the risks that threaten research security and integrity have not been made public, individual instances of undisclosed conflicts of interest and attempts to exfiltrate certain technologies have been widely reported in the press. The academic research community has called for a coordinated and harmonized approach that balances the need to address security risks with the importance of scientific openness, international collaboration, and competing for global STEM talent.

To that end, the Committee on Science, Space, and Technology developed the *Securing American Science and Technology Act* (SASTA) which was enacted through the *National Defense Authorization Act for Fiscal Year 2020*. This legislation directed the establishment of an interagency working group to

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[1] https://www.forbes.com/sites/forbesinsights/2020/01/15/diversity-confirmed-to-boost-innovation-and-financial-results/?sh=45c6ec0c4a6a
[2] https://science.house.gov/hearings/artificial-intelligence-societal-and-ethical-implications
[3] https://www.congress.gov/bill/116th-congress/house-bill/748/text
[4] https://www.congress.gov/bill/117th-congress/house-bill/1319/text
[5] https://www.congress.gov/bill/117th-congress/house-bill/144
[6] https://www.congress.gov/bill/117th-congress/house-bill/869
[7] https://trumpwhitehouse.archives.gov/wp-content/uploads/2021/01/NSTC-Research-Security-Best-Practices-Jan2021.pdf

coordinate agency action on research security and a National Academies of Science Roundtable to bring together stakeholders and experts in the law enforcement, intelligence, and national security communities with the research and academic community to facilitate discussions regarding threat mitigation.[8] The Committee also developed legislation, enacted in the *National Defense Authorization Act for Fiscal Year 2021*, to harmonize disclosure requirements and enforcement across Federal research agencies.[9]

In the final days of the Trump Administration, the Joint Committee on Research Environments (JCORE) Subcommittee on Research Security released congressionally mandated guidance to research institutions on best practices for mitigating threats to research security.[10] President Trump also issued National Security Presidential Memorandum 33 (NSPM-33) directing agencies to take steps to protect federally funded research.[11] While some stakeholders have expressed concerns about the policies put forth in NSPM-33[12], at a March 11 meeting of the National Science, Technology, and Security Roundtable, a Biden Administration official confirmed that OSTP will move forward with implementation.[13] The Committee continues to conduct oversight and advance policies to address research security.

Data Sources

NSF National Center for Science and Engineering Statistics: https://www.nsf.gov/statistics/

AAAS R&D Budget Analysis: https://www.aaas.org/news/primer-federal-rd-budget-trends

Quantifying the Immediate Effects of the COVID-19 Pandemic on Scientists

[8] https://www.congress.gov/bill/116th-congress/senate-bill/1790/text (See Sec 1746)
[9] https://www.congress.gov/bill/116th-congress/house-bill/6395/text (See Sec 223)
[1010] https://trumpwhitehouse.archives.gov/wp-content/uploads/2021/01/NSTC-Research-Security-Best-Practices-Jan2021.pdf
[11] https://trumpwhitehouse.archives.gov/presidential-actions/presidential-memorandum-united-states-government-supported-research-development-national-security-policy/
[12] https://www.cogr.edu/sites/default/files/OSTP.pdf
[1313] https://www.aip.org/fyi/2021/us-expanding-disclosure-requirements-scientists

Chairwoman JOHNSON. The hearing will come to order, and without objection, the Chair is authorized to declare recess at any time. Pursuant to *House Resolution 8*, today the Committee meeting is virtual. I look forward to when we can all get back together.

I want to announce a couple of reminders to the Members about the conduct of this remote hearing. First, Members should keep their video feed on as long as they are present in the hearing, and Members are responsible for their own microphones. Please also keep your microphones muted unless you are speaking, and finally, if Members have documents they wish to submit to the record, please email them to the Committee Clerk, whose email address has been circulated to all.

Good morning, and welcome to today's hearing and welcome to our distinguished panel of witnesses. I look forward to hearing your expert insights on how we can ensure the continued United States leadership in science and technology (S&T), and harness our research enterprise, and all of our Nation's talent to develop solutions to our most pressing challenges.

This morning, the Committee will discuss the current state of the American science and technology enterprise, the challenges posed by both increasing global competition and shortcomings in our own system, and the opportunities to reimagine and recommit to our innovation future. I understand the depth of the challenges we face, but I remain hopeful because I see the commitment, passion, and talent of our scientists, engineers, and especially our students and early career researchers. I am inspired to do everything I can to support them.

For many decades, the United States was the unquestioned leader in science and technology. This premise was firmly established through a massive investment in the 1950's and 1960's to build national laboratories and entire agencies like the National Science Foundation (NSF) and NASA (National Aeronautics and Space Administration), and to support unfettered research at U.S. universities. That commitment paid real dividends, allowing the government, the private sector, and indeed the world to reap the technological benefits.

However, since that peak, our commitment to nondefense R&D (research and development) fell rapidly, then plateaued as a share of our discretionary budget. As a share of our GDP (gross domestic product), it has continued to decline. In the meantime, many other countries have increased their investments and built innovation systems based on our own successful models. One of those on the minds of many here today is China. China is already outspending us. It may only be a matter of time before they are out-innovating us, including in critical technologies that underpin our economic and national security.

I agree that China's rise in science and technology creates real challenges for us. We have good reason to be worried about research integrity and how research will be used. However, we should not let those concerns misguide our thinking about how we will lead in the future. We will lead by doing our own best selves, not by emulating China.

In a forthcoming issue of *Issues in Science and Technology*, a scholar of innovation policy writes, "competitiveness is neither a

necessary nor a sufficient basis for equity, sustainability, or security . . . China's industrial policy has improved neither equity nor sustainability. Russia's economic collapse has done little to erode its national security." I believe we can do both. We can compete globally, and we can inspire innovation that confronts long-standing societal challenges. We can build from the institutional foundations established decades ago and work together to re-envision a bold and more inclusive model for American innovation in the 21st century.

There are a lot of big ideas to discuss, and I am sure that today's hearing will be valuable and a constructive conversation for all. In particular, we will be looking to the expertise on this panel as we continue to develop bipartisan science and innovation legislation in the coming weeks and months.

[The prepared statement of Chairwoman Johnson follows:]

Good morning and welcome to today's hearing. And welcome to our distinguished panel of witnesses. I look forward to hearing your expert insights on how we can ensure continued United States leadership in science and technology and harness our research enterprise and all of our nation's talent to develop solutions to our most pressing challenges.

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With that, I now recognize Ranking Member Lucas for his opening statement.

Chairwoman JOHNSON. And with that, I recognize our Ranking Member, the Honorable Mr. Lucas, for his opening statement.

Mr. LUCAS. Thank you, Chairwoman Johnson, for holding this hearing on the future of American innovation, and thank you for those wonderful thoughts you just offered.

I believe this is one of the most essential concerns facing our Committee, because our commitment to America's scientific progress is what underpins every other issue that comes before us, from space exploration to clean energy development, and from the strength of our economy to our national security. Our investment in basic and early stage Federal research gives us lower food prices, better healthcare treatments, cleaner and cheaper energy, and widespread access to reliable broadband internet. It just hasn't come to my farm yet in western Oklahoma. Reliable, that is.

In short, our investment in basic Federal research infrastructure and workforce development pays massive dividends. American companies use the knowledge and tools gained in our laboratories to commercialize innovations that improve our lives and our economy.

Historically, the United States has been the world's largest investor in research and development. U.S. Government and industry spent a combined $511 billion on R&S in 2016, generating over $860 billion for our Nation's economy, while supporting over 8 million jobs. As numerous studies have concluded, as much as 85 percent of the long-term growth of the American economy comes from scientific and technology advances.

But our research in science and technology is under threat. China has likely surpassed us in total R&D spending already. While they increased their research investment by 56 percent between 2011 and 2016, ours fell by 12 percent. The Chinese Communist Party has an aggressive and strategic plan for their scientific development. They have been very clear that they intend to overtake us in critical technologies. Communist leadership in China hasn't been shy about how they plan to outpace us.

In addition to outspending us, they're looking to acquire foreign research, attract premiere talent by building up world-class research infrastructure, and buildup their domestic STEM (science, technology, engineering, and mathematics) workforce. With our leadership in science and technology at risk, we need to reevaluate our commitment to the fundamentals we need to success. Basic research, cutting edge facilities, and a thriving STEM workforce.

Chairwoman Johnson and I agree on the need to support Federal research. A few weeks ago, we introduced legislation to reauthorize the National Science Foundation, along with Research and Technology Subcommittee Chairman Stevens and Ranking Member Waltz, we put forth the *NSF for the Future Act*, which increases the funding to $13 billion over 5 years. It invests in industries of the future, works to expand STEM education, and develop our STEM workforce, and includes important provisions to secure our research from foreign theft. I appreciate the bipartisan work that went into this legislation, and I look forward to working to move it forward.

It dovetails nicely with the *Securing American Leadership in Science and Technology Act*, or *SALSTA*, as I like to call it, which is legislation I've introduced to double our funding in basic research and create a national strategy to focus our investment on critical technologies like artificial intelligence (AI), cybersecurity,

and quantum computing. *SALSTA* will invent in our research infrastructure so we have the facilities required to do groundbreaking research. It helps to grow a strong American STEM pool of talent through workforce development and STEM education programs, and it makes it easier to transfer technology breakthroughs from the lab to private industry through regulatory reform. Taken together, *SALSTA* is a comprehensive and strategic approach to investing in American science and technological development.

We're still benefiting today from research investments made generations ago, and that begs the question, what investments are we making for our grandchildren and their grandchildren? Are we being strategic and forward thinking in our commitment to Federal research and development? We have a fantastic panel of witnesses here today, and I am looking forward to their insights into that question.

As a wheat farmer, I am an internal optimist. I always plant seed in the ground. I'm optimistic I'm going to make a good crop every year. And I'm also optimistic that we can work together in a bipartisan fashion to strengthen our research industry and invest in the future of our scientific development.

And with that, Madam Chairman, I yield back and enthusiastically look forward to the rest of this hearing.

[The prepared statement of Mr. Lucas follows:]

Thank you, Chairwoman Johnson, for holding this hearing on the future of American innovation.

I believe this is one of the most essential concerns facing our committee, because our commitment to America's scientific progress is what underpins every other issue that comes before us: from space exploration to clean energy development, and from the strength of our economy to our national security.

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With that, I yield back.

Chairwoman JOHNSON. Thank you very much, Mr. Lucas.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

And at this time, I'd like to introduce our witnesses. Before I do so, I would just note that they all have such distinguished careers. I depend on their voices so much that I could spend 30 minutes just introducing them. I'll try not to do that, but I would encourage everyone to read their bios.

Our first witness is Mr. Norm Augustine. Mr. Augustine was previously the chairman and CEO (chief executive officer) of Lockheed Martin, a position from which he retired in 1997. [inaudible] Secretary of the Army and Acting Secretary of the Army, among many other positions in his long and distinguished career, and a grade mark on where we are now and our future now in the scientific endeavors.

Our next witness is Dr. Frances Arnold. Dr. Arnold is the Linus Pauling Professor of Chemical Engineering, Bioengineering, and Biochemistry at the California Institute of Technology. She pioneered directed enzyme evolution, for which she was awarded the Nobel Prize in Chemistry in 2018, becoming the first American woman to do so. Dr. Arnold has also co-founded three companies and served on several private and public company boards. Dr. Arnold was recently appointed as co-chair of the President's Council of Advisors on Science and Technology.

Our third witness, the Honorable Ernest Moniz. From 2013 to 2017, Dr. Moniz served as the 13th U.S. Secretary of Energy. As secretary, he advanced energy technology innovation, nuclear security and strategic stability, cutting edge capabilities for the American scientific research community, and environmental stewardship. He is currently the President and Chief Executive Officer of Energy Futures Initiative (EFI), and a professor emeritus and Special Advisor to the president of the Massachusetts Institute of Technology (MIT).

Our final witness, Dr. Farnam Jahanian. He is currently the tenth president of Carnegie Mellon University, where he previously served as provost and chief academic officer, as well as vice presi-

dent for research. Prior to his service at Carnegie Mellon, he led the National Science Foundation Directorate for Computer and Information Science and Engineering from 2011 to 2014. He spent much of his career at the University of Michigan, during which time he co-founded an internet security company.

As our witnesses should understand we will have five minutes of spoken testimony from each of you. Your written testimony will be included in the record for the hearing, and when all of you have completed your spoken testimony, we will begin a round of questions. Each Member will have five minutes to question the panel.

So, now we will start with Mr. Augustine. You are recognized for your testimony.

TESTIMONY OF MR. NORM AUGUSTINE, FORMER CHAIRMAN AND CHIEF EXECUTIVE OFFICER OF LOCKHEED MARTIN

Mr. AUGUSTINE. Well, good morning, Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee. Thank you for the invitation to appear today.

My comments are going to draw heavily on a report, "The Perils of Complacency" which was produced by the American Academy of Arts and Sciences, an organization now almost 250 years old, in conjunction with the Rice University Baker Institute of Public Policy.

The thrust of the message is very straightforward. First, America's well-being depends heavily on having a strong economy. Second, having a strong economy depends heavily on advancements in science and technology. And third, America is on a path to lose its leadership position to China in science and technology in the not-too-distant future.

Wen Jiabao, the former Premier of the State Council of the People's Republic of China, had the following to say, and I quote, "Scientific discovery and technological inventions have brought about new civilization, modern industries, and the rise and fall of nations. I firmly believe that science is the ultimate revolution."

There have been a number of studies that have shown that up to 85 percent of the growth of the U.S. economy is due to advancements in science and technologies. Two of those studies, incidentally, were the bases of Nobel Prizes.

There are really two principal ingredients that dominate scientific advancement: financial capital and human capital. Beginning with financial capital, our current path is such that China is passing us in investments in research and development at purchasing power parity. The U.S. Federal investment in R&D has fallen from 1–1/2 percent of GDP in the 1960's to 7/10 of 1 percent today, a period of increasing impact of science and technology.

Turning to human capital, perhaps the best recognized international test of primary and secondary education is called the PISA test of 15-year-olds, it's given every 3 years. Currently, the United States places in 25th place among the developed Nations of the world in composite literary, math, and science scores.

It is noteworthy that U.S. scientific and technology enterprise today would barely function were not for foreign-born individuals who have come to our country, received their advanced degrees here, remained here, and raised their families here. These individ-

uals today provide 28 percent of the faculty of science and engineering at our universities. They provide 1/3 of the entire U.S. scientific and tech workforce. They provide 1/2 of the postdoctoral workers who perform much of our Nation's research.

I've been asked to comment briefly on military implications of these trends. I would note that China has four times the population of the United States. We are not likely to compete effectively on a personnel manpower basis with China, either militarily or economically.

Further, the history of warfare is replete with examples where technological breakthroughs have had decisive results in combat. It goes all the way back to the stirrup and the longbow to the aircraft and nuclear weapons today.

But there's another important consideration not widely acknowledged, and that is in the past much of the military advancements in science and technology are traceable to arsenals. However, today commercial technology is driving military applications. I refer, of course, to microelectronics, high speed computing, manufacturing, AI, robotics, automation, and so on.

One thing that's clear is that we can't build a wall around commercial science and technology. It's out there in the marketplace, so we have a rather simple choice. We could either be a leader, or we could be a follower.

What might be the U.S. report card in science and technology as it would exist today? In terms of quality of our research universities, we are unarguably No. 1. In terms of innovation, we've dropped from first to eighth place. R&D intensity and fraction of GDP, we've dropped from first to tenth. Primary and secondary education, we're at 25th. Professionals in R&D, per capita, 28th in the world. Fraction of research funded by the government, 29th in the world. In the fraction of initial degrees awarded in engineering we're 76th, just behind Mozambique.

Permit me a personal word in closing. My first trip to China was 44 years ago. I saw a handful of automobiles. Every adult was wearing a Mao suit. I have visited there every half dozen years or so since that time. While I don't admire many of their methods, the economic, military, and S&T results are truly astonishing. I'm 85 years old. I probably won't be around for the results of the decisions that we make today and that are being made in China. But I will note that very early in my career as a young engineer, I had the great privilege to play a very tiny part in putting 12 people on the Moon, all of whom became my friends later on. And it's truly amazing what our country could accomplish when we put our minds to it.

Thank you very much.

[The prepared statement of Mr. Augustine follows:]

Testimony Before

THE COMMITTEE ON SCIENCE, SPACE AND TECHNOLOGY

of the

U.S. HOUSE OF REPRESENTATIVES

Regarding

U.S. COMPETITIVENESS WITH THE PEOPLE'S REPUBLIC OF CHINA IN RESEARCH AND DEVELOPMENT

* * *

Washington, DC
April 15, 2021

Norman R. Augustine

Chairwoman Johnson, Ranking Member Lucas, and members of the Committee, I am honored to appear before you to discuss America's competitiveness in science and technology, particularly as relative to the People's Republic of China. With your permission I will submit a statement for the record and briefly summarize it for this hearing.

My remarks draw heavily on a report entitled, "The Perils of Complacency" that was prepared by a group of 25 leaders in a variety of fields under the aegis of the American Academy of arts and Sciences, now nearly 250 years old, and the Rice University Baker Institute of Public Policy. You had asked that I briefly comment on implications of ongoing trends in competitiveness as they affect national security. I should emphasize that my observations on that specific subject will be my own, since our group did not specifically focus on national security.

The thrust of my message today is fairly straightforward. First, America's overall wellbeing is fundamentally dependent on maintaining a strong economy. Second, maintaining a strong economy is fundamentally dependent upon advancements in science and technology. Third, America is on a path to lose its lead in science and technology to China.

China clearly understands the importance of science and technology. For example, this is what Wen Jiabao, former Premier of the State Council of the People's Republic of China had to say on the subject:

> "The history of modernization is in essence a history of scientific and technological progress. Scientific discovery and technological inventions have brought about new civilizations, modern industries, and the rise and fall of nations…I firmly believe that science is the ultimate revolution."

The Premier's perspective should not be particularly surprising inasmuch as a large segment of China's leadership in recent decades has been composed of scientists and engineers. In its Fourteenth Five-Year Plan, China has made it clear that it intends to assume global leadership in science and technology and to do so in the near future.

Change happens rapidly in science and technology. The number of transistors on a microchip has increased by a *factor* of 10 million over the past 50 years. The cost of reading a human genome dropped by a *factor* of 10 thousand over the past 13 years. Solar panel prices have been reduced by a factor of 100 million over the past 15 years.

The first cellular phone was introduced only thirteen years ago, yet today half the people on the planet, 3.5 billion people, now possess one. And a year and a half ago most Americans had never heard of COVID-19, while today new vaccines have been developed and nearly 200 million doses administered.

To lag behind the state of the art in science and technology is to risk falling out of the race altogether. We live in a golden age in science and technology, rich with opportunities spanning from artificial intelligence to quantum science, from genomics to robotics, and those who lead in discovery will lead in the opportunity to generate applications. And we have the good fortune to live in a highly dynamic economy that rewards innovation.

Further, many of the major challenges our nation faces today will likely find their solutions in science and technology. These include preserving our climate, rebuilding our infrastructure, reducing the cost of healthcare, protecting against future pandemics, securing our electric grid, and providing national defense.

My first trip to China was in 1978, and as I traveled thousands of miles around the country I saw only a handful of automobiles. *Every* adult was wearing a Mao suit. In my return trips over the years I have been astonished by what China has accomplished, including in science and technology. Which is not to say that I endorse many of their approaches. But what I have seen seems to serve as a warning—a "Sputnik Moment," if you will. But I fear that in recent years we have been more akin to frogs being slowly boiled.

A number of studies, two of which were recognized with Nobel Prizes, have shown that up to 85 percent of the growth in the U.S. economy in recent decades can be attributed to advancements in just two closely related fields: science and technology. It is, of course, our economy that makes it possible to pay for national security, social security, healthcare, infrastructure, homeland security, education, biomedical, and much, much more.

It has become fairly common to compare the financial investments of the U.S. and China in various endeavors, say R&D or national security, using standard market exchange rates. I would assert that such comparisons are often misleading. They spawn such conclusions as "the U.S. spends far more on its military than China and Russia combined…and therefore the U.S. must have a far greater military capability." As but one example of the problem with this line of thought is that, unlike China, the U.S. seeks to pay those who serve in its voluntary armed forces a wage matching that which they might receive in a "comparable civilian job"—presuming that there *is* a comparable

civilian job wherein one is on duty 24 hours a day, expected to leave one's family for years at a time, and can fully plan on being shot at during the course of their career. This difference in the cost of manpower is one element that explains how China affords a military force of 2.8 million members while that of the U.S. is about 1.2 million.

A second measure of comparison is spending as a percent of GDP, which can be useful in assessing the financial burden imposed on a nation by any particular investment, say in R&D. It can also be indicative of the emphasis a nation places on a particular activity. Arguably, still more meaningful comparisons can be made using exchange rates at purchasing power parity as a measure—which is the principal comparator used in the "Perils of Complacency" report. While an imperfect measure, it does indicate quite clearly that China has been steadily gaining on the U.S. in effective investment in R&D and can be expected to pass the U.S. by this measure in the next few years—assuming decades long policies continue to prevail in both nations.

China is already leading the world or is highly competitive in many critical fields of technology, including solar cells, energy storage, supercomputers, artificial intelligence and 5G communications.

But beyond the provision of financial resources for a nation's R&D pursuits, there is a second arguably more important factor that drives advancement in these fields: human resources. China now graduates from its universities over twice as many baccalaureate engineers as does the U.S. from its universities. This should be no surprise, given that China's population is four times that of the U.S. In fact, China passed the U.S. in the number of newly awarded science and engineering doctoral degrees some 15 years ago. The U.S. cannot hope to match the number of scientists—or soldiers—marshalled by China; rather, the U.S. must compete based upon innovation, entrepreneurship, creativity, allies, and efficiency of generating new knowledge and translating that knowledge into applications.

In China over half of baccalaureate degrees are awarded in STEM (science, technology, engineering, and mathematics) fields, whereas the comparable figure in the U.S. is 19 percent. Forty percent of K-12 students in the U.S. are underrepresented minorities that ultimately receive only 7 percent of the doctorates granted in STEM fields. Women receive 58 percent of U.S. undergraduate degrees, yet receive only 17 percent of the doctorates awarded in the U.S. in the natural sciences and engineering. The U.S. could vastly increase its number of contributing scientists and engineers were it simply to attract representative portions of all its domestic groups into the STEM fields.

In the most highly regarded international test of student performance, the PISA test, U.S. fifteen-year-olds rank 25th among 29 developed nations in combined science, mathematics and reading score. By America's own measure of achievement, the so-called "Nation's Report Card," 67 percent of fourth graders are categorized "not proficient in science." By 12th grade that share increases to 79 percent. Ironically, we spend more per pre-K-12 pupil than any other country but one. Having traveled in 130 countries and visited many schools, I find reason to share Bill Gates' observation that "When I compare our high schools to what I see when I am traveling abroad, I'm terrified for our workforce of tomorrow."

Perhaps America's most significant competitive advantage in science and technology is its collection of world-class research universities, generally considered to comprise all of the top five and 40 of the top 50 such institutions in the world. However, U.S. states recently cut funding of their universities that educate 70 percent of our college students by an average of 25 percent in real dollars during the Great Recession, making many universities quasi-private institutions…without adequate endowments. In more recent years, modest steps were taken to recover a moderate part of that lost funding. Additionally, the federal government imposed an (initially relatively modest) tax on the growth in endowments at a few of our nation's most highly regarded research universities, thereby absorbing funds that would otherwise have been available for scholarships and research—all while discouraging potential future donors to endowment funds.

How, then, has the U.S. been able to maintain such a strong competitive position in so many STEM fields in the past? A significant part of the answer resides in the fact that today's U.S. science and engineering enterprise would barely function were it not for the thousands of foreign-born individuals who came to America, received their graduate education here, raised their families here, and contributed mightily to our nation's science and engineering community.

Seventy-three percent of graduate engineering students at U.S. universities are foreign-born, as are 28 percent of science and engineering faculty, along with half of the post-doctoral workers who perform much of the nation's scientific research. Thirty percent of the overall science and technology workforce in America was foreign-born, and nearly half of the nation's Fortune 500 companies were founded by immigrants or the children of immigrants. Thirty percent of US. Nobel Laureates in the sciences were foreign-born, as were 26 percent of the individuals elected to membership in the U.S. National Academy of Sciences and 31 percent of those elected to the National Academy of Engineering.

It is vitally important that more of America's youth be motivated and qualified to pursue careers in science and engineering; yet, without continuing to attract talent from around the world there is little chance that America can remain competitive. By my calculation, were America to need one additional person performing research in the field of engineering in the year 2034, it would need to begin with a group of 3,000 eighth graders today.

Were one to create a "report card" assessing the extent of America's commitment to global leadership in science and engineering, it would look something like the following:

- Quality of research universities – 1st;
- Investment in R&D at purchasing power parity – narrowly 1st;
- Innovation – dropped from 1st to 8th;
- R&D as a percent of GDP – dropped from 1st to 10th;
- Primary and secondary education – 25th;
- Professionals in R&D, per capita – 28th;
- Fraction of research funded by government – 29th;
- Fraction of initial degrees awarded in engineering – 76th (just behind Mozambique).

I have been asked to comment on the implications of these trends as they pertain to national security. I would merely cite two factors: first, the history of warfare has been punctuated by balance-tipping technological breakthroughs: the stirrup, the longbow, gunpowder, the cannon, machine guns, tanks, battleships, aircraft, nuclear weapons, rockets, night vision, stealth, space, robotics, autonomy, cyber, and more. An example of the impact that technological dominance can have when accompanied by trained, well-led troops was to be seen during the first Gulf War when the Allied forces defeated the fourth largest army in the world in just 42 days. U.S. fatalities totaled 219.

Second, an often-overlooked factor is that in the past most advancements in defense technologies came from military arsenals; today most come from commercially available pursuits such as automation, artificial intelligence, advanced microchips, and, soon, quantum science. It will be increasingly difficult to isolate critical defense technology from the world at large—leadership will be the sine qua non.

The "Perils of Complacency" report offers a number of specific recommendations to ensure America's competitiveness well into the future, as did the earlier National Academies "Gathering Storm" report. Were I to heavily summarize those recommendations they would be to fix our nation's pre-K-12 public school system,

particularly in STEM, and substantially increase federal investment in high payoff, generally high risk, research—primarily conducted at our universities.

Finally, if you will permit a moment's personal reflection, I am now 85 years old and likely won't be around to witness the ultimate outcome of whatever decisions are made today in America and China. It would be my hope that in America we will recognize that we can no longer compete in R&D based on past investments, but will have to substantially increase our commitment to people and funding.

Earlier in my career as an aerospace engineer I had the occasion to play a very tiny role in placing twelve people, most of whom were to become my friends, on the moon. I found it truly inspiring what our nation could do when we put our minds to it.

Thank you.

NORMAN R. AUGUSTINE was born and raised in Colorado and attended Princeton University where he graduated with a BSE in Aeronautical Engineering, magna cum laude, and an MSE. He was elected to Phi Beta Kappa, Tau Beta Pi and Sigma Xi.

In 1958 he joined Douglas Aircraft where he worked as a Research Engineer, Program Manager and Chief Engineer. Beginning in 1965, he served in the Office of the Secretary of Defense as Assistant Director of Defense Research and Engineering. He joined LTV Missiles and Space Company in 1970, serving as Vice President, Advanced Programs and Marketing. In 1973 he returned to the government as Assistant Secretary of the Army for R&D and in 1975 became Under Secretary of the Army, and later Acting Secretary of the Army. Joining Martin Marietta Corporation in 1977 as Vice President of Technical Operations, he was elected as CEO in 1987 and chairman in 1988, having previously been President and COO. He served as president of Lockheed Martin Corporation upon the formation of that company in 1995, and became CEO later the same year. He retired as chairman and CEO of Lockheed Martin in 1997, at which time he became a Lecturer with the Rank of Professor on the faculty of Princeton University, where he served until 1999.

Mr. Augustine was Chairman and Principal Officer of the American Red Cross for nine years, Chairman of the Council of the National Academy of Engineering, President and Chairman of the Association of the United States Army, Chairman of the Aerospace Industries Association, and Chairman of the Defense Science Board. He is a former President of the American Institute of Aeronautics and Astronautics and the Boy Scouts of America. He serves on the Board of Trustees of the National World War II Museum and is a former member of the Board of Directors of ConocoPhillips, Black & Decker, Proctor & Gamble and Lockheed Martin, and was a member of the Board of Trustees of Colonial Williamsburg. He served as a Regent of the University System of Maryland (12 institutions), is a Trustee Emeritus of Johns Hopkins and a former member of the Board of Trustees of Princeton and MIT. He has been a member of advisory boards to the Departments of Homeland Security, Energy, Defense, Commerce, Transportation, and Health and Human Services, as well as NASA, Congress and the White House. He was a member of the Hart/Rudman Commission on National Security, and served for 16 years on the President's Council of Advisors on Science and Technology under both Republican and Democratic presidents. He is a member of the American Philosophical Society, the National Academy of Sciences and the Council on Foreign Relations, and is a Fellow of the National Academy of Arts and Sciences and the Explorers Club.

Mr. Augustine has been presented the National Medal of Technology by the President of the United States and received the Joint Chiefs of Staff Distinguished Public Service Award. He has five times received the Department of Defense's highest civilian decoration, the Distinguished Service Medal. He is co-author of *The Defense Revolution* and *Shakespeare in Charge* and author of *Augustine's Laws, Augustine's Travels* and *The Way I See It,* the latter a collection of his photography. He holds honorary degrees from 35 universities; is the Inaugural President's Distinguished Scholar of the University of Maryland Baltimore, and was selected by Who's Who in America and the Library of Congress as one of "Fifty Great Americans" on the occasion of Who's Who's fiftieth anniversary. He has delivered over 1,500 speeches and lectures and since retiring has chaired or co-chaired 41 pro bono committees and commissions, mostly for the government. He has traveled in 130 countries and stood on both the North and South Poles of the earth.

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

TESTIMONY OF DR. FRANCES H. ARNOLD, LINUS PAULING PROFESSOR OF CHEMICAL ENGINEERING, BIOENGINEERING AND BIOCHEMISTRY, CALIFORNIA INSTITUTE OF TECHNOLOGY

Dr. ARNOLD. Chairwoman Johnson, Ranking Member Lucas, Members of the Committee, first of all, thank you for supporting science and for inviting me to appear today.

As an inventor, teacher, entrepreneur, and researcher, I have seen where innovation succeeds and also how it can fail. The quest to understand our universe and our place in the natural world is one of the great manifestations of human creativity, and as we well know, such exploration is also the foundation of wealth. The rest of the world appreciates science as the driving force of prosperity, and they are making the necessary investments to compete.

Now, I've been everything from a taxi driver to a mechanical and aerospace engineer working for the nuclear industry, later building solar energy facilities. After earning a Ph.D. in chemical engineering and doing basic research in biophysics, I became a professor, an inventor, and co-founder of several companies. Now, I was never particularly expert at any of these professions, but through these diverse experiences, I acquired knowledge I could recombine to solve problems in new ways.

Inspired by the astounding feats—engineering feats of the biological world, I chose to become an engineer of that world and tune nature's machinery to do chemistry for us. And I have little doubt this will be the century of biotechnology, where we'll be able to engineer biology to make everything from pharmaceuticals, to fuels, to food, to cure cancer, and to fight pandemics.

I am but one of the many Nobel laureates this country has produced although, yes, the first woman to win the Nobel Prize in Chemistry. But importantly, I am the product of government investment in science. That funding has supported cutting edge research and trained more than 200 postgraduate researchers who are now at top universities, government laboratories, industry. And several have started companies that today employ hundreds more.

Federal grants enable seedling ideas to take shape, but not to create the many commercial products that come out of our research. Getting technology into the hands of users—in other words, making research truly useful, requires a much bigger innovation ecosystem that includes applied or development research, collaboration with industry, and entrepreneurial activities, all of which I've done. Importantly, we do not separate fundamental science aimed at understanding from research aimed at applications. To me, they go hand in hand and separation would impoverish both of them.

The strength of the academic research system in this country, in my opinion, comes from empowering younger scientists. I strongly favor portable fellowships because young people are capable of deciding where the future lies, what science fields, what problems. They will choose the universities and research settings that meet their expectations. Unrestricted grants to the most promising young researchers pay off with work that is truly innovative, rath-

er than conservative by design, because these PIs (principal investigators) are free to formulate whole new questions outside the confines of bigger projects, whose goals are already set in stone. I received such support early in my career from the Packard Foundation.

Make no mistake, not all ideas are good, nor do all such investments lead to breakthroughs, because scientists know there may be no pot of gold or Nobel Prize at the end of their little rainbow. But I believe we should reward exceptionally talented scientists who can tackle those high risk, high reward problems. And please note that all three U.S. women who've won Nobel Prizes in the sciences in the last 3 years were supported in their early years by the Packard Foundation. This is remarkable and it is not a coincidence.

I love what I do for what it can do to alleviate suffering of people and the planet. It was easier, however, 35 years ago to start a career in academic research because we did not spend 2/3 of our time in department meetings, writing proposals, or complying with regulations. Instead, we focused on research, mentoring, teaching. That has degraded. With additional responsibilities that women have with respect to family, it is very difficult to compete, almost impossible to enjoy the process. It is also a struggle for scientists from underrepresented communities, and the most talented people have multiple choices and simply take other paths.

I'm honored to be testifying before you today. I greatly appreciate the recognition each of you has given to these issues in recent legislation, and your recognition that there's more that we must do.

[The prepared statement of Dr. Arnold follows:]

Testimony of Dr. Frances H. Arnold
U.S. House of Representatives Committee on Science, Space and Technology
Hearing titled: Reimagining our innovation future
April 15, 2021

Chairwoman Johnson, Ranking Member Lucas, and members of the Science, Space and Technology Committee, thank you for your efforts in support of science and thank you for the opportunity to appear today to offer perspective on this important question: how do we cultivate science and technology to flourish in a highly competitive world, training the future workforce to enable us to continue to compete and win, while continuing to find innovative solutions to hard problems?

As an inventor, teacher, entrepreneur and researcher for the last 35 years at Caltech, a jewel of an institution and a model for many across the world who have looked on U.S. research and innovation output with envy, I have seen where scientific innovation succeeds and also how it can fail. Great science and technological innovations do not just happen—they must be nurtured, and that requires thoughtful leadership and investment in people and infrastructure. Sadly, we have not kept pace with those investments in our future, and our position as the undisputed leader of science and technology, and innovation, is looking more and more vulnerable. The quest to understand our natural universe is one of the finest manifestations of human creativity, worthy of a great culture. Such scientific exploration is also the foundation of wealth. The rest of the world appreciates the power of science and technology as the driving forces of economic prosperity, and they are making the necessary investments to compete.

I am but one of the significant number of Nobel Laureates this country has produced. However, I am the first American woman to win the Nobel Prize in Chemistry as well as the first woman to win the Charles Stark Draper Prize of the National Academy of Engineering. I have many such 'firsts' on my resume (including the first woman to appear playing herself on "The Big Bang Theory").

I am also the product of government investment in science 40 years ago.

Allow me to introduce myself by giving you a taste of the mixed set of experiences that I have been able to draw upon in my career. I have been everything from a waitress to taxi driver (fulltime for the Yellow Cab company of Pittsburgh in 1974 and part-time during college) to a mechanical and aerospace engineer working for the nuclear industry in Spain and Italy, and later building solar energy facilities in Brazil, Korea and Colorado. After earning a PhD in chemical engineering and doing basic research in biophysics, I became a professor, an inventor and co-founder of several companies. I was never particularly expert at any of these professions, but through these diverse experiences I acquired resilience and learned how to adapt to a rapidly changing world. Importantly, I acquired skills and knowledge that I could recombine to solve problems in a unique way. I did not follow any one else's path to science, but I did require the support of many along the way.

I am an engineer inspired by the astounding engineering feats of the biological world. The most complicated engineered systems on this planet were not designed by human engineers. They are the products of 4 billion years of evolution. I chose to become an engineer of this biological world, with the goal of tuning Nature's catalytic machinery to do clean chemistry for us. The problem was that no one knew how to do this. I chose to use the design process that Nature invented, evolution, to explore where biological systems could promote human wellbeing. My 'test tube evolution' worked very well, in fact, for rewriting the code of life, and the rest is, well, history. With the powerful tools we now have for manipulating biology, including CRISPR gene editing for which the Nobel Prize in Chemistry was awarded in 2020 to another American woman, I have little doubt that this will be the century of biotechnology. We will be able to engineer biology to make everything from pharmaceuticals to fuels to food, to cure cancer, and to fight pandemics.

Role of federal grant support

My work has largely relied upon research funding provided by federal government agencies, especially the National Science Foundation in the early stages, but also the NIH, DOE, Office of Naval Research and Army Research Laboratory. That funding supported not only cutting edge science, but contributed to training more than 200 postgraduate researchers who themselves are now at top universities, government laboratories, and industry. Several have started their own companies that today employ hundreds more.

The federal research grants which enabled my seedling ideas to take shape were not sufficient to create the many commercial products that have eventually come out of our research. Getting products and technology into the hands of users, making research truly useful in other words, requires a much bigger innovation ecosystem. In rare cases, my research laboratory can simply pass a technology or product directly to industry for commercialization, but this only happens when existing or anticipated short-term industry needs are matched to the invention. It is much more often the case that technology transfer requires a development phase, especially for innovative technologies not directed to filling a company's current needs. Sometimes we can start that development phase in the academic setting, taking a demonstration to a level where industry starts to see short-term commercial value. But often development requires a different set of skills, a larger level of investment than we can conjure up, or involves timelines and milestones not compatible with the open structure of a university, where teaching, training and knowledge transfer are also critical functions. Maybe a start-up company can do it, but that requires people with very different skills...and money. The people are often harder to find than the money.

The federal government, which supports this science enterprise responsible for so much of U.S. innovation over the last 75 years, has an incentive to ensure that the knowledge and ideas created are advanced when appropriate. Ways to do this are, on a small scale, to expand federal grants that support the seedling idea stage or proof of concept and, on a larger scale, to focus resources around laboratories of innovation – the kind that bring in ideas from different fields, ideas from different types of stakeholders, and skills from across the science and commercial ecosystems. Traditionally, our nation's basic research agencies, namely NSF and NIH, aren't set up to focus on either of these ends of the spectrum. Yet, increasingly, this is what's required to move at the pace of innovation or

replicate successful models from the past and present. Competition is extremely healthy for maintaining a vibrant science and innovation ecosystem—ideas that are not competitive should be allowed to die, but it is a shame when a brilliant idea dies before it even has a chance to compete.

Academic structure and innovation

My group's research is highly interdisciplinary, cutting across engineering, chemistry, biology and computer science, and our contribution to molecular engineering by directing evolution likely would not have been possible within a traditional academic research structure. As a young engineer with little experience in molecular biology, I was trying to do what structural and computational biologists thought only they could and should do, engineer new protein sequences using the new tools of molecular biology. But I was at Caltech, in a chemistry division that created new disciplines all the time. I could reach out to top biologists to learn new methods of manipulating DNA, and top chemists would share their insights into the most challenging problems. Importantly, colleagues simultaneously criticized my approach and challenged me to reach higher. I could recruit students and postdocs from across all the disciplines needed to establish the breadth of science and technology that our work would require. This continues today as we transition from fully empirical evolution to using the data in machine learning-guided enzyme engineering, a field that did not even exist when I was trained. The students trained in this environment are fully equipped to do fundamental research as well as solve real-world problems. These students also know how to learn and are in a position to lead science and technology in a rapidly changing world.

Importantly, we do not separate fundamental science aimed at understanding the natural world from research that is aimed at specific applications. To me they go hand in hand, and separation would impoverish both.

The nature of the institutional structure is important. In fact, it is the lack of structure (at least the classic academic form with departments set in prehistoric stone) that promotes creativity. Unfortunately, the world, and for that matter just about everything else, changes faster than academic structures. As a result, research leaders have to actively overcome barriers to cross-disciplinary work and training. This can change with good leadership and understanding of what drives innovation. A carefully designed structure can promote diversity of thought and creative problem solving from the bottom up without enforcing silos of entitled researchers who are terrified by change.

Building a broader science workforce

The most insidious barrier to innovation is hierarchy. The strength of the academic research system in this country comes from the empowerment of younger scientists—assistant professors are fully responsible for their own work, for better or for worse. It is also important to empower researchers when they are still undergraduate and graduate students so that they can experience the joy of being a research scientist or engineer. Such empowerment is inherently dynamic and actively combats hierarchy and ossification. I favor supporting the most talented of our young people with portable fellowships for graduate study, because they are fully capable of deciding where the future lies—what science fields, what problems—and they will choose the universities

and research settings that meet their expectations. A combination of support across science, focused in strategic areas, and to the best of our youth will pay off many times over in the generation of science and engineering leaders. Fellowships and non- or less-restricted grants to the most promising young research leaders will allow and even encourage them to take risks and will pay off with research that is truly innovative rather than conservative by design. These individual PIs are thereby freed to formulate whole new questions outside the confines of big projects whose goals are already set in stone.

I was fortunate to receive support with few constraints early in my faculty career in the form of an NSF Presidential Young Investigator award and a transformational 5-year fellowship from the Packard Foundation. Such support encouraged exploration of new ideas, before they were competitive for a grant and therefore for which there were few means of support. Make no mistake, not all ideas are good, nor do all such investments lead to breakthroughs. Just as entrepreneurs and venture capitalists know that most startups are doomed to fail, scientists know that there may be no pot of gold, or Nobel Prize, at the end of their little rainbow. But rather than reverting to the mean and funding only the most conservative of proposals, as happens far too often now, I believe we should reward exceptionally talented scientists who have identified ways to tackle the high-risk, high-reward problems. An interesting piece of information: all three US women who have won Nobel Prizes in the sciences since 2018 were supported in their early years by the Packard Foundation. This is remarkable, and it is not a coincidence.

I wish to point out that it is this competitive vibrancy of our academic enterprise that attracts the brightest students from all over the world to U.S. universities for PhD and postdoctoral studies. Our research programs are greatly enriched by these international students, who often stay to make their careers in the U.S., where they see the opportunity to compete without political, cultural or other limitations experienced in their home countries. This great brain attraction enhances the U.S. science enterprise as well as the innovation ecosystem: we only need to look at the large fraction of Nobel Laureates, national medalists, and founders of high technology companies who are immigrants to appreciate this. They are risk-takers and value the opportunity to do it here. We should continue to welcome them and their contributions.

I have talked mainly about science as a competitive enterprise, often led by elite institutions such as Caltech. That should not be surprising, because this is from where my experience derives. I cannot leave, however, without talking about diversifying the scientific workforce beyond those coming from elite research universities. Cutting-edge science is not limited to the elite institutions. Competition that leads to excellence is good for science, but there are ways to help level the playing field for the excellent programs that are not at the most elite universities. For example, I believe that portable fellowships can help to level the playing field, as could fellowships directed to geographical areas (still allowing students to choose specific mentors and fields of research) serve to support the best regional programs. Similarly, adding or reserving prestigious fellowships and early career awards for Minority Serving Institutions and emerging research institutions will ensure that some of those promising faculty have the same head start from which I benefitted and provide an opportunity for their students to train under a creative environment. This is not about

awarding those who are less deserving but finally seeing those who have been deserving all along. This is the only way we can truly change the system. Finally, there are challenges best understood, tackled, and scaled on a regional level (e.g. feedstocks to help usher in a new bioeconomy or energy supply, integration, and resiliency), leveraging local ecosystems or circumstances or talent pools. These are just some of the ways in which the federal government should more fully engage on this issue. I know you all share my concerns and belief that talent exists all over this country, and it is incumbent upon us to foster it for the benefit of the nation.

Moreover, consideration should be given to the importance of programs aimed at scaling up and building out entrepreneurial corps among our nation's scientists and thought leaders. While care should be taken to only do this where the problems are important and where entrepreneurial or industrial investment and commitment are lacking, we must acknowledge that the next generations will not follow a linear path in their careers. Where there is interest, we should foster scientists and engineers who are both interested in studying a problem and potentially seeing those ideas implemented for the benefit of society.

It is very challenging, however, to become a scientist or engineer, especially if one falls behind in math and science in middle and high school. Talent is evenly distributed, but access to quality education in this country is not. Thus the pipeline is constricted by access already in early years. On the other side of the pipe, science and engineering need to compete with other careers that may be attracting the brightest students from all groups. The more that young people can see the kind of impact they can make through science and engineering, the more they will be willing to pursue this career. Therefore, we scientists need to tell our stories better and not hide in the quiet ivory tower. No PI has a 'right' to taxpayer money to support their personal curiosity quest—we all have an obligation to give back, in one form or another. Enhanced understanding of our universe can give back just as much as a potential cure for a disease, but the story must be told. And, all of these quests should involve and train the next generation of scientists and engineers.

Finally, let me offer a little bit of my perspective as a woman. I love what I do for what it can do to alleviate suffering of people and the planet. I never based my career choices on how much money I could earn, but instead on the degree to which I would be free to learn and determine my own trajectory and impact. It was easier, however, 35 years ago to start a career in academic research—we did not spend two-thirds of our time in department meetings, writing proposals or making sure we were complying with regulations. Instead, we focused on research, mentoring, and teaching. That has degraded. With additional responsibilities that women have with respect to family, it is very difficult to compete, and almost impossible to enjoy the process. The competitive environment that has been highly effective for finding competitive scientists is not always the best for finding the most effective scientists, especially where teamwork is critical. The most talented people have multiple choices, and they take other paths.

Research scientists don't earn huge salaries; younger academic scientists and those still in training earn much less than their contemporaries who chose lucrative careers in law or finance or even those who don't go on for advanced degrees. Childcare, as you know, is very expensive and is

usually beyond the means of a graduate student or postdoctoral researcher, forcing many young women in particular to choose between a research career and family. Would-be researchers from less-privileged backgrounds face similar challenges.

I am honored to be testifying before this Committee today. I appreciate the recognition that each of you has given to these issues in recent legislation and your further recognition that we must do more if we are to solve the hard challenges of tomorrow.

Frances Arnold is the Linus Pauling Professor of Chemical Engineering, Bioengineering and Biochemistry at the California Institute of Technology. Arnold pioneered directed enzyme evolution, for which she was awarded the Nobel Prize in Chemistry in 2018 (the first American woman to do so); she has used directed protein evolution for applications in alternative energy, chemicals, and medicine. Arnold was recently appointed to co-chair the President's Council of Advisors on Science and Technology. Among other awards, Arnold has received the Charles Stark Draper Prize of the US National Academy of Engineering (2011), the US National Medal of Technology and Innovation (2011), and the Millennium Technology Prize (2016). She was the first woman elected to all three US National Academies of Science, Medicine, and Engineering and was appointed to the Pontifical Academy of Sciences in 2019. Co-inventor on more than 60 patents, Arnold was inducted into the US Inventors Hall of Fame in 2014. She co-founded three companies in sustainable chemistry and renewable energy (Gevo, Provivi, Aralez Bio) and serves on several public and private company boards. She earned a B.S. in Mechanical and Aerospace Engineering from Princeton University and a Ph.D. in Chemical Engineering from the University of California, Berkeley.

Mr. BERA. I don't know if we lost the chairwoman. Can we get——

Ms. STEVENS. Yeah, it looks like Chair Johnson is not there.

Mr. BERA. Should we go to the next witness?

Ms. STEVENS. Yeah, Secretary Moniz.

TESTIMONY OF THE HONORABLE ERNEST J. MONIZ, PRESIDENT AND CHIEF EXECUTIVE OFFICER, ENERGY FUTURES INITIATIVE AND FORMER SECRETARY, U.S. DEPARTMENT OF ENERGY

Mr. BERA. Secretary, you're on mute.

Mr. MONIZ. Yeah, the most famous expression of the new age, you're on mute. Thank you.

OK. Madam Chair, Ranking Member Lucas, Members of the Committee, thank you for the opportunity to testify before you today.

Many countries have committed to net zero carbon emissions by mid-century, and the U.S. will soon release a new ambitious interim target for emissions reductions by 2030. A decade of supercharged innovation is needed, starting now, in order to have a chance of meeting these goals.

It's important to place the associated investments in a larger context: the changing risk profile, the growing interdependencies of critical infrastructures, the growing importance of supply chains, and regional differences and needs. Traditional weather risk profiles are no longer adequate. The modernized climate risk disclosure needs to be supported by research with sufficient regional granularity for the full spectrum of extreme weather events. Electricity, natural gas, and water systems are interdependent, and innovation in systems analysis is needed badly. The need to address supply chain issues was underscored by President Biden's Executive order on American supply chains. Critical minerals and metals availability are a major challenge and needs innovation.

The administration has proposed an ambition innovation agenda. Federal energy innovation should expand the Federal Government's innovation role beyond early stage R&D, address key breakthrough technology areas, improve coordination across the Federal Government, harness the full range of tools for Federal support, bring together public and private innovation players, support regional innovation, build on and supercharge successful innovation structures like ARPA-E (Advanced Research Projects Agency—Energy) and the Energy Frontier Research Centers.

The *Energy Act of 2020* marks a significant move to advance and accelerate the energy innovation agenda. It authorized new energy RD&D (research, development, and deployment) efforts in seven major titles, and emphasized the importance of Federal support for demonstration projects.

Internationally, the current focus of mission innovation should be expanded to include emerging technologies for carbon dioxide removal (CDR) and advanced nuclear energy, both fission and fusion.

RD&D areas that merit additional support include cross cutting technologies that reduce emissions in multiple sectors and strengthen the foundation of the innovation infrastructure.

A few examples are clean hydrogen, sustainable supply chains, climate risk analysis tools, and as a complement to emissions mitigation, carbon dioxide removal, and in addition to direct air capture, emphasis should be extended to other CDR pathways and multiple Federal agency roles.

A 2019 EFI IHS study also identified the importance of so-called platform technologies as an enabler of innovation for clean energy and multiple other sectors. Key platform technologies include additive manufacturing, materials by design, artificial intelligence, and big data analytics, genomic science and synthetic biology, and much more.

A greatly enhanced platform technologies initiative could be led by NSF with important contributions from DOE (Department of Energy), DOD, Commerce, NIST (National Institute of Standards and Technology), HHS (Health and Human Services), NIH (National Institutes of Health), and others in a whole of government approach.

The architecture and processes for implementation of a Federal energy innovation investment program are also important. First, innovation investment programs should build upon and better integrate the existing unparalleled innovation capacity in the United States across private industry, universities, research institutions, entrepreneurs, and Federal, State, local, and tribal government entities. Federal policies should encourage public/private partnerships, formation of regional innovation ecosystems, and alignment of innovation investment with market formation policies.

Second, it's essential that the innovation portfolio support the entire innovation spectrum from use-inspired fundamental research through learning by doing demonstrations and pioneering commercialization. The innovation process is not a simple linear process. There's an opportunity to further expand the NSF role beyond discovery science to support use-inspired fundamental research in areas of science and engineering, especially in platform technologies that cut across many applications. However, adding a major focus on technology development and commercialization to NSF's mission would be a major risk to the nature and culture of the agency, and would been to be circumscribed with great care.

A great example of use-inspired research comes from DOE. Energy Frontier Research Centers focus on fundamental research, and yet, have produced significant advancements in the technology base toward commercialization. ARPA-E has also been successful in bridging the gap and deserves more funding.

The future role of NSF in use-inspired fundamental research should be complementary to and closely coordinated with similar fundamental research at DOE and other Federal mission agencies. The innovation agenda calls for better alignment of the policies, players, and programs that are the key building blocks of our national energy innovation ecosystem.

Madam Chair, Ranking Member Lucas, Members of the Committee, I look forward to your questions.

[The prepared statement of Mr. Moniz follows:]

Testimony of Secretary Ernest Moniz, CEO, Energy Futures Initiative before the House Committee on Science, Space and Technology April 15, 2021

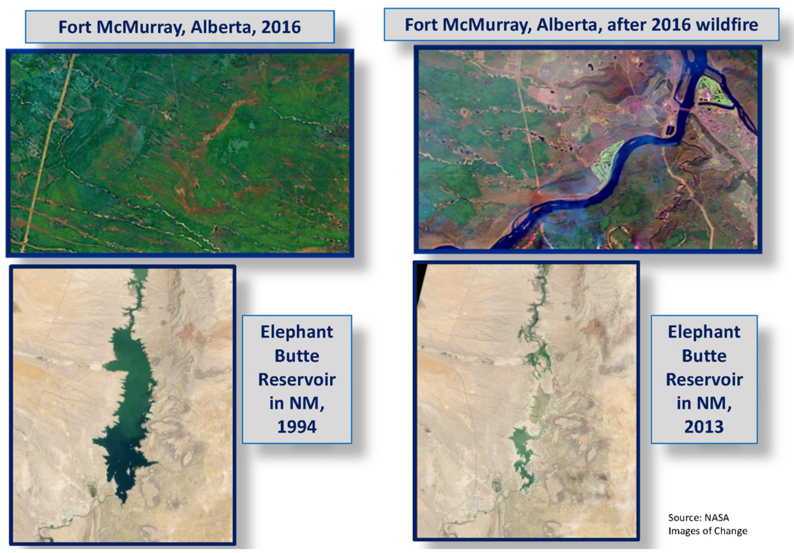
Madam Chair, Ranking Member Lucas, members of the Committee, thank you for the opportunity to testify before you today.

The US is approaching 600,000 deaths from the COVID pandemic. The loss of decades old businesses, millions of jobs, and the overall impacts of the pandemic on the US and global economy are without parallel in modern times.

At the same time, the world is facing another crisis of global and existential proportions: climate change. Its impacts and their growing severity are becoming increasingly clear. According to NOAA, 2011–2020 was the warmest decade on record for the globe, with a surface global temperature of 1.48°F above the 20th century average. Every month of 2020 except December was in the top four warmest on record for that month.

There are, as we have seen, a range of physical impacts of these temperature increases – rising sea levels, increased frequency and intensity of storms, increased drought, declining water supplies, melting glaciers, increased wildfires, greater extremes of both heat and cold. Figure 1 offers graphic pictures taken by NASA of the impacts of wildfires and droughts in North America. The science is clear, and the data are compelling—climate change is a major threat to our planet and to our way of life, and the clock is ticking.

Figure 1. Examples of the Impacts of Climate Change In N. America: Increased Wildfires, Severe Drought



The growing severity of these changes – and the urgent signals they are sending -- has not gone unnoticed by the world's nations. In 2015, 197 countries adopted the Paris agreement. According to the UNFCC,

191 countries have submitted their first Nationally Determined Contribution (NDC) and eight have submitted their second.[i] Importantly, since Paris, the number of countries that have implemented or are considering net zero emissions targets, now stands at 130, up from around 17 just two years ago.

This is true in the US as well, where the Biden Administration is setting us on a new and accelerated course towards an economy with net zero greenhouse gas (GHG) emissions by mid-century. The U.S. has rejoined Paris and within a matter of days, it is expected that the Administration will release an updated ambitious Nationally Determined Contribution setting a new interim target for GHG reductions by 2030. I applaud these actions and look forward to working on ways the US can meet these increased ambitions and to highlight these and other U.S. actions at COP 26 in Glasgow later this year.

Critical Context for Guiding Innovation Investments

There is a range of responses that are needed to address the climate crisis but today I would like to focus on one: the critical need for technology innovations to address both the growing impacts of climate change and the increased ambitions of most of the world's nations, including the United States. As the science of climate change has advanced and the changes in the impacts of climate become more manifest and severe, the Energy Futures Initiative's analysis has increasingly focused on those innovations that are central to any climate action plan that can succeed in reaching the aggressive—but essential—net-zero goal.

Before I discuss some of the innovations that will be key to deep decarbonization, I think it is important to place the associated investments in a larger context as we consider the portfolio of technologies needed to meet net zero targets by mid-century. These include: the changing risk profile; the growing interdependencies of critical infrastructures; the potential, indeed likely, changes in our work environment, post-COVID; the growing importance of supply chains; and regional differences and needs.

- ***The changing risk profile***. In the last two years, two of our largest states – Texas and California – have been devastated by the impacts of climate change. Wildfires in California forced the preemptive shutdown of large sections of the state's grid. Last August, a western US extreme heat wave forced rolling blackouts in California. More recently in Texas, the extreme cold snap left much of the state without power and heat. These and other events suggest that weather and other risk profiles that have guided infrastructure protection, development, and investments are no longer adequate for risk assessment, associated policy actions, and infrastructure investments in the future. Yesterday's weather is no longer a good guide for planning to meet tomorrow's weather extremes

  Late last month, the Financial Stability Oversight Council met; its agenda included a discussion of climate risk and the implications of this risk for the nation's financial systems. The SEC, Federal Reserve and CFTC are all analyzing options on disclosure of climate risks. The Federal Reserve is working to "…understand the potential implications of climate change for financial institutions, infrastructure and markets." These activities need to be supported by research to update climate risk assessments in order to better guide investment planning and disclosure requirements. These actions also reinforce the ESG focus of shareholders and institutional investors. Taken together, we anticipate profound shifts in corporate priorities in the direction of accelerating the response to climate change.

- ***The complex interdependencies of critical infrastructures***. Preliminary analysis of what went wrong in Texas, from a systems perspective, suggests that the natural gas, electricity, and water systems were all affected by the extreme cold and that their interdependencies were major contributors to the electricity crisis.

This is not surprising. The first installment of the Quadrennial Energy Review, released in in 2015, included a section specifically focused on the 2011 cold snap in Texas and New Mexico, emphasizing the growing interdependencies of the electricity and natural gas infrastructures, borne out by the events in Texas 10 years later (see Text Box 1).

Text Box 1. QER 1.1 Highlighted Gas/Electric Infrastructure Interdependencies

The Big Chill: A Disruptive Event Made Worse by Infrastructure Interdependencies[i]

The "Big Chill" of 2011 illustrates the complicated relationship between natural gas and electric power, which had compounding effects during a period of extreme weather.

During the first week of February 2011, the U.S. Southwest was hit by an arctic cold front that was unusually severe in terms of its low temperatures, gusting winds, geographic extent, and duration. From January 31 to February 4, temperatures in Texas, New Mexico, and Arizona were the coldest experienced within the region since 1971. Dubbed the "Big Chill" in the media, it overwhelmed the routine preparations for cold weather that had been put in place by electric generators and natural gas utilities located in those states.

Within the Electric Reliability Council of Texas (ERCOT) Interconnection, starting in the early morning hours of February 2, the cold temperatures and wind chill caused a significant number of outages at generating plants, with approximately one-third of the total ERCOT generating fleet unavailable at the lowest point of the event. With electricity demand soaring because of the cold weather, ERCOT and some utilities in New Mexico instituted rolling blackouts to prevent collapse of their electric systems. For the Southwest as a whole, 67 percent of electric generator failures (by megawatt-hour) were due directly to weather-related causes, including frozen sensing lines, frozen equipment, frozen water lines, frozen valves, blade icing, and low-temperature cutoff limits on equipment.

Gas producers and pipelines were also affected in Texas, New Mexico, and Arizona. Natural gas production was diminished due to freeze-offs and the inability to reach gas wells (due to icy roads) to remove produced water and thereby keep them in operation. When rolling electricity blackouts hit gas producers and gas pipelines, it had the effect of causing further losses to natural gas supply. The ERCOT blackouts or customer curtailments caused or contributed to 29 percent of natural gas production outages in the Permian Basin and 27 percent of the production outages in the Fort Worth Basin, principally as a result of shutting down electric pumping units or compressors on gathering lines. As a result of all these factors, natural gas deliveries were affected throughout Texas and New Mexico. More than 30,000 customers experienced natural gas outages at some point during this period.

The majority of the problems experienced by the many generators that tripped, had their power output reduced, or failed to start during the event were attributable, either directly or indirectly, to the cold weather itself. However, at least another 12 percent of these problems were attributed afterward to the interdependencies between gas and electricity infrastructures (such as lost electricity generation due to natural gas curtailments to gas-fired generators and difficulties in fuel switching).

[i] Federal Energy Regulatory Commission and North American Electric Reliability Corporation. "Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1-5, 2011: Causes and Recommendations." August 2011. http://www.ferc.gov/legal/staff-reports/08-16-11-report.pdf. Accessed February 2, 2015.

- ***The growing importance of supply chains***. Increased electrification, new clean energy technologies, LNG exports to allies, and COVID have raised issues about the security of global supply chains and the need to focus on creating, building, and reinvigorating domestic options. Increased electrification and the buildout of transmission lines and variable renewable generation technologies will, for example, mean dramatic increases in demand for steel, EV battery manufacturing, the mining, processing, and refining of key metals and minerals including lithium, cobalt, manganese, and nickel, and cathode and anode production. Also, this demand growth is not occurring in a vacuum. Net zero targets are increasing demand—and competition—for steel, EVs, batteries, and other key materials and technologies around the world.

  The need to address these issues was underscored by President Biden's Executive Order 14017, America's Supply Chains, which notes that "More resilient supply chains are secure and diverse—facilitating greater domestic production, a range of supply, built-in redundancies, adequate stockpiles, safe and secure digital networks, and a world-class American manufacturing base and workforce. Moreover, close cooperation on resilient supply chains with allies and partners who share our values will foster collective economic and national security and strengthen the capacity to respond to international disasters and emergencies."

- ***Changes in the work environment, post-COVID.*** While no one knows for certain how the unprecedented experience of the pandemic will affect the work environment of the future, it appears likely that there will be dramatic increases in the numbers of people working from home. This could have significant implications for energy needs and the associated infrastructures to support the changed workplace.

  First and foremost, it could require increased demand for reliable and resilient electricity supplies as productivity will be directly linked to power availability. It may also lower energy demand for transportation at the same time it could increase residential electricity demand; peak electricity demand profiles could change. In addition, it would require universal access to broadband to ensure

all Americans have equal workplace flexibility options. The COVID crisis drove this point home: children without access to broadband could not "go to school". Businesses without access to broadband couldn't meet customer needs. Finally, the increased use of broadband and the internet to conduct business could increase concerns about cyber-security. Innovation investments should consider this changing profile and address these needs. An overarching point: continued electrification of the economy ups the ante for reliability, resilience, security and power quality of the electric grid.

- ***Regional differences and needs.*** Last, and perhaps most important for the members who represent varied constituencies across the country, the resources, infrastructures, emissions profiles, innovation, and policy needs vary greatly by region of the country—a "one size fits all" approach will likely impede, not accelerate progress towards deep decarbonization. EV charging infrastructures will, for example, look very different in both rural and urban areas, where the typical "suburban EV model mindset" and its associated infrastructure will have little relevance to densely populated cities and sparsely populated regions of the country. Industrial centers in the U.S. will have ongoing need for high quality process heat that cannot easily be provided by electricity. Many regions have sequestration options, some do not. Offshore wind resources are clearly available only to those regions with coastlines, and onshore wind resources vary greatly across the country as do solar resources. They also have large seasonal variations.

The Need for a Decade of Super-charged Innovation

Energy innovation is the essence of America's security and strength. Our ability to innovate is at the heart of American economic success and optimism. It is essential for national security, addresses complex societal challenges and improves our quality of life. It is critical for addressing the existential threat of climate change. Central to U.S. leadership in innovation is our unparalleled innovation ecosystem which includes the Federal, state, local and tribal governments; national laboratories; research universities; the private sector; nonprofits and philanthropies

Several groups, including the American Energy Innovation Council comprised of CEOs of large American companies, have argued for tripling federal clean energy investment. The Biden Administration has proposed an even more ambitious agenda—the President's request for FY 2022 discretionary funding includes more than $10 billion, a 35 percent increase over FY 2021, for clean energy innovation across all non-defense agencies. Further, as stated in the budget summary, "The 2022 discretionary request puts the Nation on a path to quadruple clean energy research Government-wide in four years."[1] The federal energy innovation portfolio—indeed the portfolio across the entire innovation chain—needs to be "all of the above" to match time scales and geographies and to emphasize optionality. History shows that we achieve better results when flexible innovation pathways are favored over planned, prescriptive outcomes.

This broad approach is critical as we accelerate clean energy innovation investments – both public and private -- over the next decade or so. Maximum optionality and flexibility will be needed to address the needs of different regions and of all end use sectors—including the industrial, heavy transportation and agricultural sectors that are hard to decarbonize. Breakthrough technologies will be needed.

Innovation can also drive job creation, which is essential as we come out of the COVID crisis with a need to create millions of good jobs. These are bipartisan opportunities to create clean energy jobs and strengthen our country, where coalitions — labor and business, environmental groups and financial institutions, religious and military leaders, public and private sectors, Republicans and Democrats, and others — are needed to accelerate legislative solutions to the climate challenge.

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[1] U.S. Office of Management and Budget, Letter from Acting Director Shalanda D. Young to Senate and House Leadership, April 9, 2021.

Accelerating this transformation, however, will not be easy. U.S. energy systems are highly capitalized and provide essential services. making them risk averse and prone to considerable inertia. This creates an inherent tension between the energy incumbents and the technology disruptors; mitigating this tension through innovation, thoughtful policies, and creating clean energy job options is essential for a more rapid transition to deeply decarbonized energy systems and end use sectors.

Innovation is at the Core of Climate Change and Infrastructure Modernization. As noted, there will be no single nor simple solution to meet net zero emissions. While the key technological near-term strategies to move towards net zero may be generally understood (policy support is a separate and less clear-cut issue), many that may be currently available could benefit from further improvements in performance and cost. Also, many of the technology solutions needed to meet mid-century targets are not yet available, a conclusion specific to California that was made in the EFI study, *Optionality, Flexibility & Innovation: Pathways for Deep Decarbonization in California,*'' released in May, 2019.

Electricity storage is a case in point. Deployment of electricity storage systems is only in its earliest stage. Current commercial battery storage technology typically provides from 4-6 hours of storage; other options may provide longer duration storage but are site-specific, limited by geography or geology. Large scale deployment of intermittent carbon free electricity generation will require significant levels of longer duration storage capable of meeting daily, weekly, and even seasonal variations. The 2019 California study illustrates the challenges associated with limited-duration storage, seen in Figure 2.

Figure 2. California Wind and Solar Generation for Each Day of 2017, CA Installed Storage Capacity, 2019

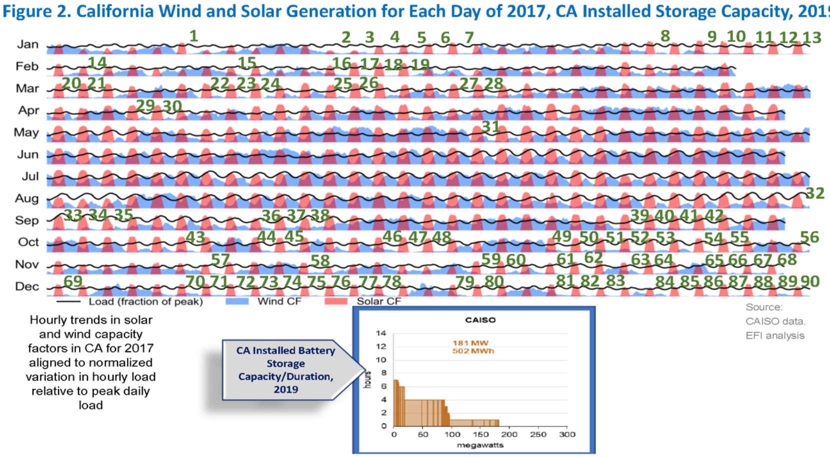


Figure 2 shows the hourly wind and solar generation for every day in 2017. Numbers in green count the days in the year where there was little to no wind generation in the state. The inset shows the installed battery storage capacity and duration in California which is currently insufficient to provide longer duration storage during multi-day periods with little to no wind generation.

The recent *Clean Energy Innovation Report* from the International Energy Agency provides a global context for immediate action on clean energy investment. The report emphasizes that while energy efficiency and renewable energy will be crucial, they are not sufficient to meet net-zero climate goals, especially in sectors like heavy industry and transportation.

The IEA Report also estimates that, on a global level, at least 40 percent of emissions reductions to reach net zero will rely on technologies not yet at commercial scale—including known technologies such as end-use electrification, CCUS, hydrogen, and bioenergy. In the study, IEA also stresses that action is necessary immediately because past innovations, such as LEDs and lithium-ion batteries, took decades to reach full commercialization, and some energy-consuming infrastructure operates on refurbishment cycles of 25-30 years.

There is also a large body of analytical evidence about the need for increased *national* investment – both public and private - across the full spectrum of energy innovation, from use-inspired fundamental research through demonstration and initial deployment. Various metrics have been used to assess the adequacy of investment in energy innovation. The 2019 Report by EFI and IHS-Markit, *Advancing the Landscape of Clean Energy Innovation,* estimated that global private R&D spending in the energy industry is substantially lower, both in dollars and in share of revenue, than in other major industries.

Looking at trends in government investment, federal energy R&D spending has been decreasing as a share of GDP. Federal energy R&D spending also lags other areas of federal R&D. A recent study by Columbia University Center for Global Energy Policy, for example, noted that federal energy R&D spending is less than one quarter the level for health care R&D and less than 10 percent of national defense R&D spending.

These issues have been documented in other studies as well, and the resulting recommendations have been clear and consistent. Also, the American Energy Innovation Council (AEIC) noted that government investment fills an essential niche by funding innovation where "the private sector cannot or will not."[2]

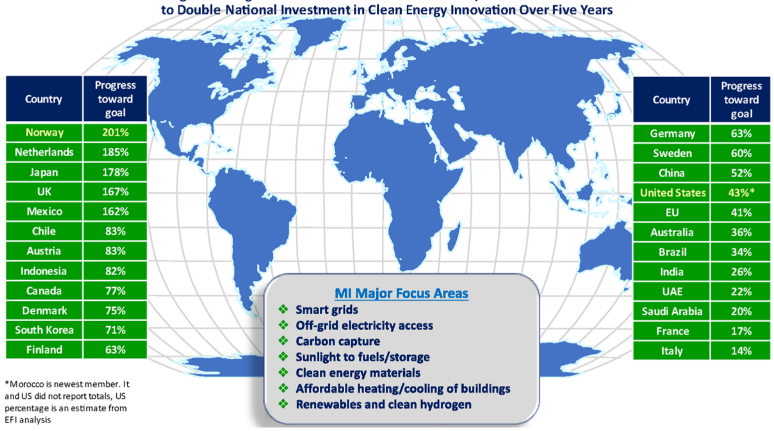
There is significant consensus from these and other reports on recommendations for federal energy innovation support that include:

- Expand the federal government's innovation role beyond early-stage R&D to fund demonstration, as well as establish complementary programs to promote deployment
- Fund new or vastly expanded innovation programs in key breakthrough technology areas
- Improve coordination across the federal government and expand the decarbonization innovation mission beyond DOE
- Harness the full range of tools for federal support, such as loan guarantees, financing support, tax credits, and procurement
- Create programs that can unlock funding from the private sector and collaborations that bring together public and private innovation resources
- Collaborate with state, Tribal, and local governments to support regional innovation, in many cases building on DOE national laboratory support
- Build on and supercharge successful innovation structures like ARPA-E, DOE Innovation Hubs, and Energy Frontier Research Centers

As Secretary, I led the effort to develop Mission Innovation, a collaborative commitment by 24 countries as well as the European Union to double the level of public investment of national governments in clean energy innovation over a five-year period. Mission Innovation was highlighted by national leaders at the first day of COP-21, a key companion effort to support the Paris Agreement. The Trump Administration did not follow-through on that commitment, and instead sought to cut DOE applied energy R&D programs dramatically in successive budget proposals over the past four years. Fortunately, Congress rejected those proposals and instead provided sustained growth in the DOE energy investment portfolio in the face of these headwinds, but at a slower pace than envisioned in the Mission Innovation commitment. As the most recent Mission Innovation scorecard shows (Figure 3), the U.S. public investment increased by over 43% over the first four years of Mission Innovation, but at a slower pace than 15 of the 24 Mission Innovation countries, including China.

2 American Energy Innovation Council, *Energy Innovation: Fueling America's Economic Engine* (Washington, D.C., 2018)

Figure 3. Progress of Mission Innovation Countries/EU on 2015 Commitment to Double National Investment in Clean Energy Innovation Over Five Years



Country	Progress toward goal
Norway	201%
Netherlands	185%
Japan	178%
UK	167%
Mexico	162%
Chile	83%
Austria	83%
Indonesia	82%
Canada	77%
Denmark	75%
South Korea	71%
Finland	63%

Country	Progress toward goal
Germany	63%
Sweden	60%
China	52%
United States	43%*
EU	41%
Australia	36%
Brazil	34%
India	26%
UAE	22%
Saudi Arabia	20%
France	17%
Italy	14%

*Morocco is newest member. It and US did not report totals, US percentage is an estimate from EFI analysis

Successful innovation requires sustained multi-year investment, and action by the Administration and Congress to revitalize and enhance the U.S. commitment to Mission Innovation. As part of this effort, the current seven focus areas of Mission Innovation noted in Figure 3 also should be expanded to include emerging promising technologies for carbon dioxide removal and advanced nuclear fission and fusion energy technologies.

A robust Mission Innovation program will not only be essential to any new agreement that will emerge at COP-26 in Glasgow, but also will serve to strengthen our global energy security posture. In 2014 after the Russian incursion in Ukraine, as Secretary I led an effort to develop the "G-7 Energy Security Principles" to move the U.S. and its allies off the decades-old oil-centric definition of energy security. The new, modernized view of energy security incorporates conventional energy as well as clean energy risks and, for the first time, formalizes the geopolitical security risks of climate change. These principles were adopted by G-7 energy ministers in Rome and by G-7 and EU leaders later that year in Brussels. The modernized principles, summarized in Figure 4, acknowledge the importance of clean energy as an enabler of energy security and underscore the high value of clean energy innovation as an enduring contributor to global security (highlighted in green)

Figure 4. Energy Security Principles Adopted by G-7/EU Leaders, 2014

- Flexible, transparent and competitive energy markets, including gas markets, should be developed.
- Infrastructure modernization will improve energy system resilience. Promoting supply and demand policies will help withstand systemic shocks.
- Energy fuels, sources and routes should be diversified and development of indigenous sources of energy supply should be encouraged.
- Reducing our greenhouse gas emissions and accelerating the transition to a low carbon economy are key contributors to enduring energy security.
- Energy efficiency in demand and supply, and demand response management should be enhanced.
- **Deployment of clean and sustainable energy technologies and continued investment in research and innovation should be promoted.**
- Emergency response systems, including reserves and fuel substitution for importing countries, should be put in place to manage major energy disruptions.

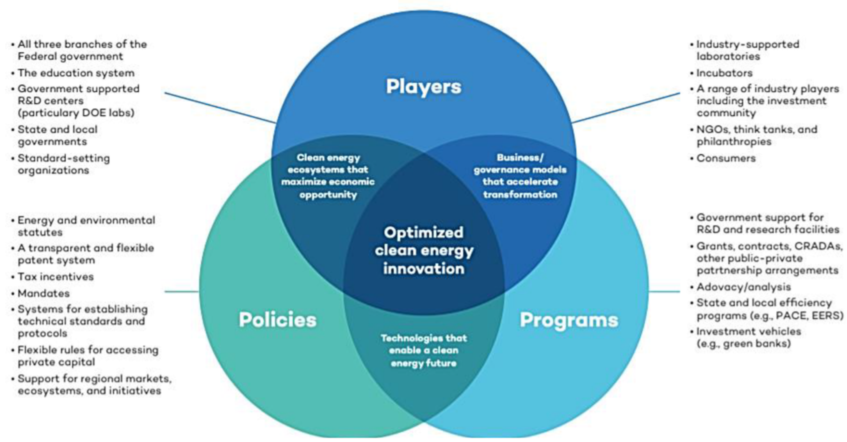
Adopted from Joint Statement, Rome G7 Initiative for Energy Security, May, 2014

Portfolio Elements for a Supercharged Innovation Program

The U.S. clean energy innovation system is unparalleled. It includes extensive collaboration among all levels of government, national laboratories, research and academic institutions, and the private sector. To ensure the U.S. economy reaches net zero carbon by midcentury, there must be a supercharging of clean energy innovation. This means increased, and more targeted, public, and private sector investment and close alignment across all stages of innovation—from basic research through demonstrations and deployment.

Federally supported and led energy innovation research depends on close alignment of activities across agencies, regardless of appropriated amounts. A key focus is the Department of Energy, which has historically administered the lion's share of Federal investment in clean energy innovation. Other agencies, however, have and must continue to play a significant role in clean energy innovation. These include the National Science Foundation (NSF), Department of Defense (DOD), the Department of Transportation (DOT), and the Department of Agriculture (USDA); portfolios at these agencies have different areas of focus—each important to support the overall innovation system. Figure 5 depicts how the alignment of key players in both the public and private sector, policies and programs can help optimize clean energy innovation.

Figure 5. Aligning the Key Players, Policies, and Programs Can Optimize Clean Energy Innovation



At the core of success in developing the technologies and systems needed to reach a carbon neutral economy by midcentury is a robust clean energy innovation portfolio. Developing a portfolio based on any single variable, such as cost, may be inadequate. Some sectors, such as aviation and manufacturing, are more difficult to decarbonize than others but will require significant attention, innovation spending, and other types of policy, regulatory, and business model support. There are also significant systems integration needs that cannot be met if innovation investments are too narrowly focused.

Breakthrough Technology Evaluation Criteria. *Advancing the Landscape of Clean Energy Innovation* study described the importance of a systematic method for planning a comprehensive RD&D portfolio. The

report provided a four-step methodology for identifying breakthrough technologies to address national and global challenges and help meet near-, mid-, and long-term clean energy goals as seen in Figure 6.

Figure 6. EFI's Four-Step Methodology for Identifying Breakthrough Technology Areas[3]

The following are expanded definitions of these technology selection criteria:

- **Technical Merit** includes energy or environmental performance, especially GHG reduction, leading to systems-level performance improvements. It also includes enabling innovations or knowledge and heuristic gains for cost, risk, and performance across a variety of technologies or systems.
- **Market Viability** includes manufacturability at scale with adequate and secure supply chains; a viable cost-benefit ratio for providers, consumers, and the greater economy; maturity to support very large scale-up; economic and environmental sustainability from a life-cycle perspective; significant market penetration; and revenue generation.
- **Compatibility** includes potential to interface with a wide variety of existing energy infrastructures (interoperability); potential to adapt to a variety of possible energy system development pathways (flexibility); potential to expand or extend applications beyond initial beachhead applications (extensibility); and the ability to minimize stranded assets.
- **Consumer Value** takes into consideration potential consumer preference issues, such as expanded consumer choice (by facilitating the introduction of new or improved products and services) and ease of use.

Shortlist of Breakthrough Technology Areas. The EFI/IHS-Markit study identified five broad technology areas deemed to have high breakthrough potential, including:

1) advanced battery and long-duration energy storage technologies;
2) Deep decarbonization: large scale carbon management;
    a. Carbon capture, use and storage at scale
    b. Sunlight to fuels
    c. Biological sequestration
3) Technology applications of industry and buildings as sectors that are difficult to decarbonize;
    a. Hydrogen

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3 https://static1.squarespace.com/static/58ec123cb3db2bd94e057628/t/5e56b4e66212a045e9892505/1582740734147/Advancing+the+Landscape+of+Clean+Energy+Innovation.2+2019.pdf Page 78

    b. Advanced Manufacturing Technologies
    c. Building energy technologies
4) advanced nuclear reactors;
5) platform technologies, such as AI, machine learning and big data analytics;
6) Systems: electric grid modernization and smart cities.

The process of technology innovation is dynamic, and over the past several years several other new technology areas with breakthrough potential have emerged including:

1) Technological and technologically enhanced carbon dioxide removal;
2) Nuclear fission micro-reactors; and
3) Nuclear fusion technologies

Progress is being made. The Energy Act of 2020 marks a significant move to advance and accelerate the energy innovation agenda. The Act also authorized a series of measures to improve DOE management of the innovation process. In addition, the Act authorized new energy RD&D efforts in seven major titles that largely mirror the breakthrough technology areas identified above, including:

- Energy Efficiency
- Nuclear Energy
- Renewable Energy and Storage
- Carbon Management
- Carbon Removal
- Industrial and Manufacturing Technologies
- Critical Materials; and
- Grid Modernization

The Energy Act of 2020 also emphasized the importance of federal support for demonstration projects as a critical need in the end-to-end innovation (i.e., RD&D) cycle for next generation clean energy technologies. Government policies and programs that enhance learning across the innovation chain should be built out and encouraged. The authorizations in the Energy Act were accompanied by increased appropriations to translate these directives into action. For example, more than $400 million dollars was appropriated to demonstration projects across these key technology portfolio elements, including $250 million for the Advanced Reactor Demonstration Program; and $115 million for SMR development, design, and demonstration. The consideration of the supply chain and jobs needs—both are key to later stages of the innovation system— promote long-term success. Wind energy programs, for example, received significant funding for offshore and distributed systems, advanced manufacturing of component parts, grid integration, and job training.

Enabling Platform Technologies. The 2019 EFI/HIS-Markit study also identified the importance of so-called platform technologies as an enabler of energy technology innovation. The rapid development of digital, data-driven, and smart systems—largely from outside the energy sector—has unlocked the potential of other platform technologies that could be scalable across the entire energy value chain. Key platform technologies include:

- Additive manufacturing, enabling more efficient and customized fabrication of products at smaller production scales;
- Materials by design, utilizing computational methods to enable more rapid prototyping of materials to meet specialized requirements;
- Artificial intelligence and big data analytics to provide new insights into many applications ranging from optimization of industrial processes to improved reliability of the electricity grid;
- Genomic science and synthetic biology, to develop new biomass energy sources, enhanced carbon capture pathways and to substitute biological for chemical processes; and
- Blockchain, to enhance the integrity of databases and provide better tracking of transactions throughout the supply chain.

A greatly enhanced focus on these platform technologies could be led by NSF, with important contributions from DOE, DOD Commerce/NIST, HHS/NIH and others in a whole of government approach.

Priority Areas of Emphasis. Federal agencies must work closely with the private sector to ensure the evolving policy environment, climate science, and financial and investment trends factor into the innovation programs and the technology portfolio. RD&D areas that merit additional support include cross-cutting technologies that reduce emissions in multiple sectors and strengthen the foundation of the innovation infrastructure. A few examples are: clean hydrogen; sustainable supply chains; climate risk analysis tools; and carbon dioxide removal.

Clean Hydrogen. Hydrogen is a clean energy carrier with multiple applications across every sector of the economy. Clean hydrogen could play an essential role in a low carbon economy as a zero-carbon "fuel" and was identified as one of ten technologies with significant breakthrough potential in *"Advancing the Landscape of Clean Energy Innovation."*

EFI analysis in 2019 also concluded that hydrogen was one of four cross-cutting clean energy pathways that could help California meet its mid-century net zero targets. The Energy Act of 2020 provides a strong foundation to build a robust hydrogen ecosystem in the United States through appropriations to study the benefits of blue hydrogen, research methods to reduce hydrogen transportation costs, and advance fuel cell technologies, among others.

There is significant interest among investors, utilities, oil and gas companies, and heavy industry to be part of the hydrogen solution. Opportunities for clean hydrogen end uses include industrial processes, heavy transportation, and power generation. Hydrogen from natural gas steam methane reforming (SMR) processes are already mature and meet almost all current domestic hydrogen demand. Producing "blue hydrogen" by capturing the carbon emitted via this hydrogen production approach is an off-the-shelf clean hydrogen solution. Using clean electricity to produce "green hydrogen" is also commercially available but requires further innovation to reduce costs.

As with carbon capture and sequestration, large hydrogen users may have the business expertise and capital availability to support an end-to-end hydrogen supply chain for their own uses. For clean hydrogen to scale, however, new infrastructure investments will likely be required to enable market hubs where several producers and consumers are co-located and benefit from economies of scale.

The infrastructures needed for hydrogen market formation tend to be highly regional. Potential large-scale consumers, such steel, and power generation, tend to be in close-proximity, and are already supported by pipelines, power lines, roads, and other infrastructures needed for the clean energy transition. Finding similar synergies with other infrastructure needs for achieving deep decarbonization, including carbon capture and storage from a range of facilities, could lower the overall development costs of a hydrogen-fueled economy at the same time they provide pathways for a net zero future. These potential "hubs" could be formed in regions where various users of hydrogen across industrial, transport and energy markets are co-located and could benefit from shared infrastructure.

Targeted additional support would allow the U.S. to accelerate the development of clean hydrogen as a versatile energy source and the resultant decarbonization benefits. Regional-based studies of the range of hydrogen production pathways and viable market and regulatory structures is an important area that deserves additional support. Green hydrogen production pathways, which use clean electricity resources to produce hydrogen, are an important option for regions that lack suitable geologic storage capacity. Deploying hydrogen transport, storage, and fueling infrastructure will be critical to realize U.S. decarbonization goals, and region-specific plans will likely be needed to account for variable regional aspects such as geological storage potential and energy demand. A transition to clean hydrogen will also require preparing a workforce trained to handle hydrogen from production through end-use and ensuring that such jobs provide competitive wages. Finally, a national, economy-wide roadmap for the deployment of hydrogen across all relevant sectors should be developed, establishing multi-year goals and R&D initiatives focused both on technology advances and accelerating market penetration.

Sustainable Supply Chains. Supply chain issues of new clean energy technologies must be evaluated and factored into policy plans. Favoring certain clean energy pathways without considering the potential material and process limitations could delay or hinder U.S., and global, decarbonization efforts.

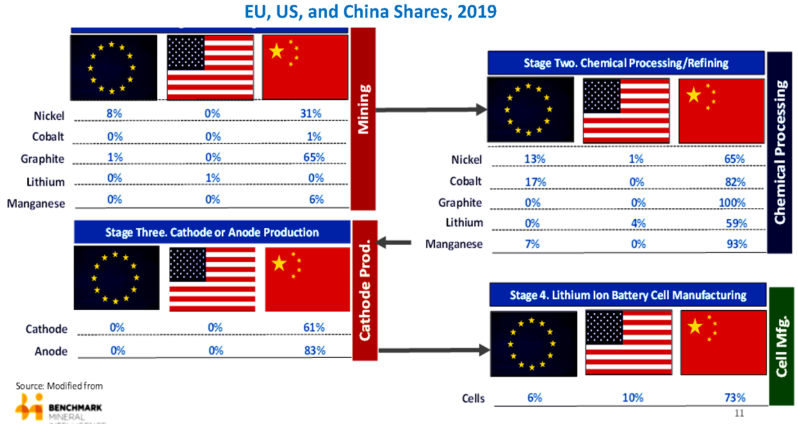
Policies and programs that could enhance US capacity in these areas include:

- protection of global supply chains for minerals/metals needed for wind, solar and batteries;
- support for innovation to support new domestic, environmentally responsible, net-zero mining activities for key minerals/metals, including associated infrastructures;
- an increase in the capacities, capabilities, and associated infrastructures needed for key mineral chemical processing/refining and battery manufacturing;
- significant recycling programs for key metals and minerals; and
- research into substitutions for key minerals by earth-abundant metals and minerals.

Much of the innovation in this area has been led by the private sector, and additional private investment in these areas is much needed. A key requirement to foster increased private sector innovation is the protection of intellectual property rights. Federal policy to protect the rights of innovators has its roots in the U.S. Constitution, which calls for the government "to promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries." This principle was recently tested in the dispute between LG Energy Solutions (LGES) and SK Innovation (SKI) over the misappropriation of proprietary LGES EV battery trade secrets by SKI and destruction of pertinent records. Fortunately, the Biden Administration stepped in to facilitate a settlement between the two companies that maintained the integrity of IP protection policy while enabling the expansion of domestic manufacturing of EV battery systems and protecting jobs to support the electrification of the U.S. light duty vehicle market.

Figure 7 underscores the need for innovation throughout the supply chain for the metals and minerals supply chain for EV battery manufacturing. The heavy reliance on foreign supply at key points in the supply chain point to the need for RD&D and associated deployment policies to support net-zero domestic mining, chemical processing and refining, and manufacturing of electric vehicle lithium-ion batteries.

Figure 7. Select Process for Key Metals and Minerals Needed for EV Battery Production: EU, US, and China Shares, 2019



Title VII of the Energy Act of 2020 promotes a robust effort to rebuild domestic supply chains, emphasizing responsible production and efficient use, recycling, and development of alternatives for critical metals and minerals. In particular the establishment of a robust program for assessment of critical metals and minerals is an essential first step. The Act also authorizes DOE to conduct a comprehensive program of RD&D as well as commercial application for critical materials, including development of alternatives, recycling and efficient production and use. These efforts should expand to include all materials vital to the clean energy transition. Onshoring offshore wind supply chains, for example, including raw material extraction, manufacturing, and final assembly could generate thousands of good jobs that would generate significant regional economic activity.

New Climate Risk Frameworks. While Earth has seen major climate variation over its history, the pace of change today is well beyond that attributable to natural phenomena and is driven by human activity, especially from energy. The UN's 2019 Climate Action Summit brief noted that the last four years were the four hottest on record, and winter temperatures in the Arctic have risen by 3°C since 1990. The growing intensity and frequency of floods, hurricanes, and droughts across the country and the world have underscored both the ferocity and costs of a changing climate. As noted, a recent example is the winter storm in mid-February 2021 that affected large regions of the southern U.S., including Texas, with sustained subzero temperatures and snow. In Dallas, in February temperatures were -2 degrees F, while the average low for this time of year was around 40 degrees. Because two-thirds of Texans rely on electric heating, this led to a surge in electricity demand throughout the state of about 20 GWs, or one-third of the winter peak, far exceeding ERCOT's worst case planning scenario, based on the 2011 winter storm. In other words, we can no longer look at the past to predict the future.

It is critical that we develop a new, flexible climate risk profile for energy systems and the broader economy, including the associated analytical tools. This is an area that needs significant innovation investments in new models, techniques, and approaches for considering climate change-based risk into the system. It is critical that multi-agency efforts, with support from universities, the national labs, and other research institutions continue to develop tools, programs, and partnerships that closely monitor climate conditions, feeding into decision making processes in both the public and private sectors. The risk profiles need to be developed with regional granularity not just for polar vortices but for the entire spectrum of weather and other climate change extremes.

Carbon Dioxide Removal. CDR is an essential complement to CO2 emissions reductions, and a critical part of achieving net-zero emissions goals and subsequently net-negative emissions, thereby providing the opportunity to reverse some of the effects of historical GHG emissions. In EFI's 2019 report *Clearing the Air*, EFI outlined a 10-year, $10.7-billion RD&D program to bring more CDR approaches to deployment readiness—a necessary step to scaling up CDR to the point where it can make a meaningful difference. We believe that CDR is a necessary and material contributor to any successful pathway to net zero, and certainly for achieving a net negative emissions economy.

The Energy Act of 2020 establishes a broad-based CDR RD&D program to "…test, validate, or improve technologies and strategies to remove carbon dioxide from the atmosphere on a large scale." The Act also established prize program for direct air capture and authorized the Secretary of Energy to establish an interagency task force and report to Congress on additional CDR measures. These provisions track closely with the EFI Report recommendations. In addition, Congress made a historic investment in CDR RD&D in the December omnibus, with appropriations totaling over $90 million for RD&D on technological and technologically enhanced natural CDR pathways.

A significant increase in appropriations will be needed in future years to reach the funding levels recommended by the 2018 National Academy of Sciences Report and the 2019 EFI Report. Furthermore, current authorization and appropriations for CDR emphasize DOE programs for direct air capture as the principal CDR pathway. Additional emphasis should be extended to other CDR pathways, and other federal agency roles, including bioenergy with carbon capture (BECCS), and bioengineered plants, forestry, and soil pathways (with USDA); in situ and ex situ carbon mineralization (with Interior and EPA); and ocean-based CDR involving both biological and chemical methods (with NOAA). In December 2020,

EFI issued a series of three supplemental reports on terrestrial CDR, oceans-based CDR and carbon mineralization.[4]

Targeted pilot testing and demonstration programs will be a critical element for assessing the feasibility and suitability of CDR for large scale deployment. EFI proposed a competitive, technology-neutral demonstration projects fund in *Clearing the Air*. And while the extension of the 45Q tax credit in the Energy Act of 2020 was critical to provide necessary incentive for deployment of both CDR as well as carbon capture, utilization and storage (CCUS) from point source emissions, proposals for expanding 45Q, enhancing its credit for CDR projects, and new tax credits for natural CDR pathways such as expanded tree-planting should be further explored.

Cyber-Security. Ensuring cybersecurity must be a fundamental consideration when modernizing and expanding U.S. energy infrastructures. The modern energy system—including the electric grid, natural gas systems, on-road and air transport, and manufacturing—will become increasingly dependent upon cyber-physical systems. As the energy system becomes smarter through the integration of information and operational technologies, the risks posed by cyber-attacks will increase.

There are, however, also opportunities to engineer cybersecurity into the future energy infrastructure in a way that supports decarbonization, operational resilience, and security. This will include developing intrusion detection systems into critical components, expanding our capability to monitor and track the supply chains for critical components, embedding cybersecurity into training across the entire workforce, building on our strong information sharing programs between the government and private sector and among industry itself. The recently revealed SolarWinds attack shows how cybersecurity must be applied along the entire supply chain for infrastructures. These and other measures should be integrated into how we build energy infrastructure in the United States.

Implementation Framework for a Super-Charged Clean Energy Innovation Portfolio

The architecture and processes for implementation of a federal energy innovation investment program are as important as the content of the portfolio itself. Drawing upon my experience in academia, government and now in the private sector, I offer several general principles for consideration.

First, innovation investment programs should build upon and better integrate the existing unparalleled innovation capacity in the U.S. across private industry, universities, research institutions, entrepreneurs and federal, state and local government entities. Stepping up the pace of energy innovation requires building upon the collaborative strengths of this innovation ecosystem. Increased federal investment in innovation can best accelerate the clean energy transition by leveraging all of the players into closer alignment. This can be accomplished through federal policies that encourage public-private partnerships, formation of regional innovation ecosystems and alignment of innovation investment with market formation policies.

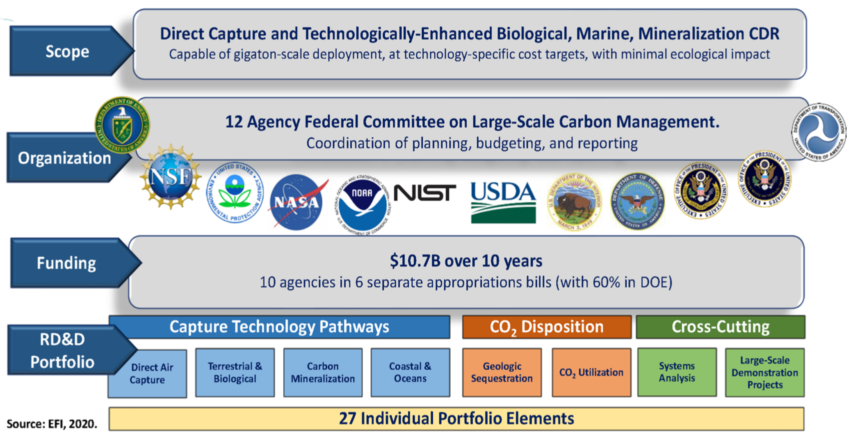
The private sector is central to clean energy innovation, providing entrepreneurial vision, channeling financial resources, and connecting innovation to the rest of the energy system and the economy. The private sector is not only a key player in innovation, but also is key to testing and early adoption of innovations emerging from government and academia. Public private partnerships, leveraged by federal cost sharing and other policy initiatives, can expand and accelerate the ability of the private sector to deliver innovative energy products and services to consumers.

States, Cities and Tribal governments play a very important role in the energy innovation process, particularly as supporters of initial commercial adoption of new energy technologies and products. Expanded policy innovation in state electricity and natural gas regulatory practices also could play an important role in accelerating energy innovation.

[4] The three reports are: *From the Ground Up: Cutting-Edge Approaches for Land-Based Carbon Dioxide Removal; Uncharted Waters: Expanding the Options for Carbon Dioxide Removal in Coastal and Ocean Environments;* and *Rock Solid: Harnessing Mineralization for Large-Scale Carbon Management.*

As noted, at the federal government level, a key focus is the Department of Energy, which in FY 2016 administered three-quarters of Federal investment in clean energy innovation. Other agencies with significant clean energy innovation budgets include the Department of Defense (DOD), the Department of Transportation (DOT), and the Department of Agriculture (USDA); portfolios at these agencies are mission-focused, as opposed to being broadly based across all energy sectors. It is imperative that major energy innovation programs will utilize a whole-of-government approach. Carbon dioxide removal (CDR) represents a case in point. The EFI 2019 Report, *Clearing the Air*, provided a set of recommendations and detailed implementation plans for a comprehensive, 10-year, $10.7 billion research, development, and demonstration (RD&D) initiative in the U.S. to bring new pathways for technologically enhanced CDR to readiness for widespread application. The wide range of scientific challenges requires an interagency effort spanning the mission responsibilities of 12 federal departments and agencies, with DOE, the Department of Agriculture and the National Oceanic and Atmospheric Administration playing key roles (Figure 8).

Figure 8. Comprehensive Carbon Dioxide Removal RD&D Initiative



Source: EFI, 2020.

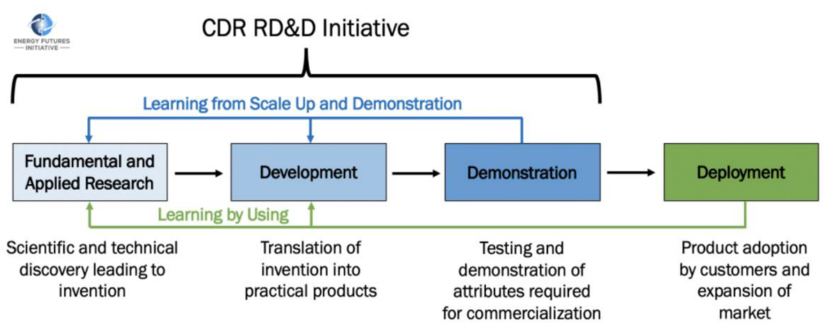
The effective planning, budgeting, and execution of the CDR RD&D initiative will require effective coordination led by the Office of Science and Technology (OSTP) and the Office of Management and Budget (OMB). This coordination effort is modeled from the highly successful U.S. Global Change Research Program. Similar interagency coordination mechanism may need to be strengthened in other areas of energy innovation such as advanced manufacturing technology.

Within the federal energy innovation establishment, the 17 DOE National Laboratories play a critical role. The National Laboratories provide world-class research facilities that are too expensive and specialized to be developed by universities or most companies acting alone, and by providing sustained attention to scientific issues with long time horizons and multidisciplinary complexity. Notably, five of the world's ten fastest supercomputers are housed in National Laboratories. The National Laboratories also play an

important integration role among the participants in the energy innovation process, through various collaborative programs that help connect the early scientific discovery emphasis of research universities with the needs of industry for near-term solutions.

Second, it is essential that the innovation portfolio support the entire innovation spectrum, from use-inspired fundamental research through learning-by-doing demonstrations and pioneering commercialization. As shown in Figure 9, the innovation process is not a simple, linear process of (i.e., early-stage government research followed by private sector development, demonstration, and commercialization), but rather a complex process where the feedback loops can be as or more significant. A federal system that is focused solely on discovery and invention leaves the door open to other countries to translate the fruits of this research into new products, industries and jobs that are based offshore.

Figure 9. Focus of a CDR RD&D Initiative



The process of moving innovations into the marketplace generally follows these four stages; however, this process can be non-linear as a result of feedbacks stemming from technology scale up, demonstrations, and learning by using. Source: EFI, 2019.

It is essential that the federal investment portfolio support innovation in all areas. Additional investment is needed in fundamental research that will feed the pipeline for future innovation. Within DOE, the Office of Science has supported a broad program of fundamental research, including operation of large scientific user facilities that are used by university and private sector researchers (many of the university users are NSF supported). Over the past decade the Office of Science has developed a program of use-inspired fundamental research[5] through the establishment of Energy Frontier Research Centers (EFRCs). The design of this program was the outgrowth of a series of in-depth workshop meetings of the science community convened by DOE beginning in 2001 to identify areas of fundamental research needed to support energy technology breakthroughs. The workshops led to the 2007 Basic Energy Sciences Advisory Committee Report, *Directing Matter and Energy: Five Challenges for Science and the Imagination.*

[5] Use-inspired science has been referred to as Pasteur's Quadrant—an approach fitting to DOE and Mission Agencies. See Donald E. Stokes, Pasteur's Quadrant: Basic Science and Technological Innovation, Washington, DC, Brookings Institution Press, 1997.

It should be noted that the EFRCs were largely university based with some partnerships with the private sector and other research participants. While the focus of the EFRC program was on fundamental research, it produced significant advancements in the technology base to support subsequent commercialization. This connection is illustrated by the fact that DOE reports that EFRC research has led to more than 650 invention disclosures and 180 patents, with 100 companies having directly benefited from EFRC direct partnerships, patent licensing, and transfers of scientific findings to technology developers.

In this regard, the National Science Foundation (NSF) also can play a critical role through its established network of research university-based principal investigators and collaborative research centers. While the NSF is appropriately focused on fundamental research, and should remain so, there is an opportunity to further expand the NSF role beyond discovery science to support use-inspired fundamental research in areas of science and engineering that can accelerate technology innovation, especially in platform technologies, such as advanced computation, synthetic biology, cybersecurity, risk assessment and decision science that underpin many potential inventions of and applications to new products and services. Adding a major focus on technology development and commercialization to NSF's mission, however, would pose a major risk to the nature and culture of the agency and would need to be circumscribed with great care. The provisions in the draft House bill, *The National Science Foundation for the Future Act,* to erect a firewall between a new NSF Directorate for Science and Engineering Solutions and the existing organization are reflections of such risk.

The DOE and its system of National Laboratories play an important role in planning and implementing use-inspired fundamental research initiatives. DOE has provided leadership in platform technology areas including high performance computing, the National Quantum Initiative, artificial intelligence, cybersecurity, biotechnology and genomics. In addition, DOE has the ability to manage both open science and classified applications concurrently, a critical programmatic feature. The future role NSF in use-inspired fundamental research should be complementary to, and closely coordinated with, similar fundamental research in DOE and other federal mission departments and agencies, including joint programs, to enhance opportunities for translation of research into applied technology development, demonstration, and ultimate commercialization by the mission agencies and the private sector.

At the other end of the spectrum, government cost shared support for prototyping and demonstration projects at or near commercial scale are equally important to test the operational viability and commercial attractiveness of new technologies. The expanded list of advanced energy technology demonstration projects authorized in the Energy Act of 2020 underscores the important federal role in supporting technology scale-up and demonstration projects, and implementation of these provisions will provide significant momentum for energy innovation over the coming years.

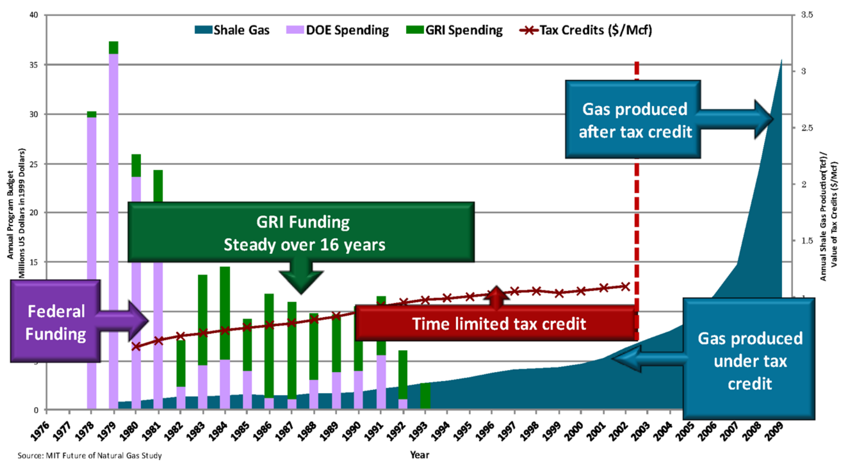
Finally, the role of the Advanced Research Projects Agency—Energy (ARPA-E) is noteworthy for its unique role in bridging between the stages of fundamental and applied research into development and scale-up. ARPA-E, established in the America COMPETES Act of 2007 pursuant to a recommendation by the National Academies of Science, Engineering and Medicine in the *Rising Above the Gathering Storm* Report, has been given more program flexibility than other DOE applied energy R&D programs to spur acceleration of innovation in cutting edge areas of energy technology. The success of ARPA-E has been widely acknowledged in various metrics on patents, follow-up investment and formation of new companies.

The ARPA-E mission and functions were favorably evaluated in the June 2017 report by the National Academies, *An Evaluation of ARPA-E*. The FY 2021 Energy and Water Development Appropriations Act raised the annual funding level to $427 million, but it is still less than half the level recommended at the time of its establishment over a decade ago. This has led to suboptimal award rates, with many good ideas left on the table. Increased funding for ARPA-E should be considered as one of the highest priorities for Congress in the new budget cycle. Consideration also should be given to broadening its programmatic reach, by allowing ARPA-E for example to increase the length and size of grant awards. The Biden Administration request for FY 2022 discretionary funding includes a total of $1 billion combined for both

ARPA-E and the proposed Advanced Research Projects Agency—Climate (ARPA-C). No additional details are yet available as to the allocation between the two entities or to the proposed portfolio for ARPA-C.

Third, the innovation portfolio needs to be closely coupled to deployment incentives. The development of the U.S. shale gas industry offers a textbook example of how strategic investments in innovation, coupled with public-private partnerships and targeted, time-limited financial incentives, can work together to successfully launch a major energy transition. As seen in the Figure 10, federal investments in technology development in drilling technology and federally funded resource assessments provided the foundation for development of shale gas (and oil) technology.

Figure 10. Federal Investment Policies, Industry Support: US is Now the Number One Gas Producer in the World



Follow-on applied R&D investment, through a public private partnership involving DOE, the Gas Research Institute (now the Gas Technology Institute) and the private sector achieved proof of concept of shale gas drilling techniques. The availability of the nonconventional gas tax credit provided an important incentive to encourage the initial deployment. The industry then matured on the basis of learning-by-doing improvements in productivity. This same model may be relevant to the development of the advanced nuclear technology and the offshore wind industries.

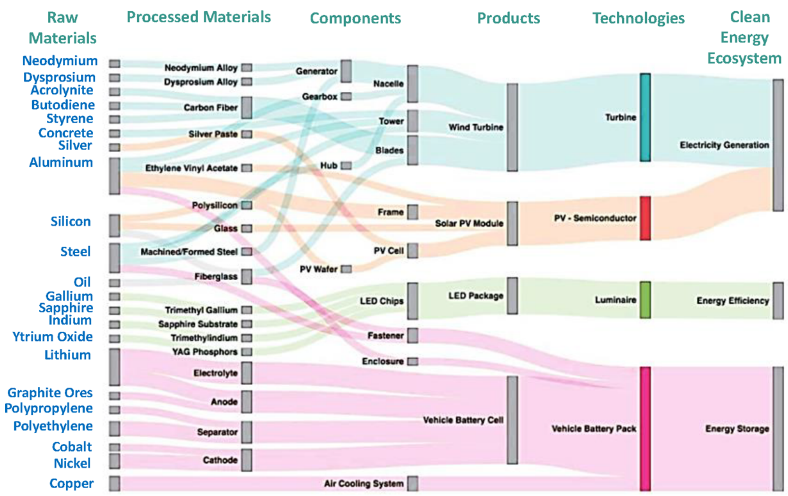
Fourth, energy innovation programs need to provide greater emphasis on supply chain issues. As noted earlier, advanced clean energy technologies are increasing dependent upon critical metals and minerals, as shown in Figure 11.

Meeting the increased demand for critical metals and minerals will likely require a corresponding-increase in domestic mining, albeit mining that employs environmentally sustainable practices. It will also require the development of stable, strategic international supply chains. Targeted RD&D activities can supplement these strategies. Opportunities for materials substitution and materials recycling, as well as alternative approaches for materials processing and equipment manufacturing should become a requirement for all DOE funded RD&D for clean energy technologies. Strategies for commercial

deployment should take into consideration security and reliability of supply chains and develop appropriate acquisition strategie

Fifth, the implementation of energy innovation programs needs to be cognizant of regional variations

Figure 11. Sankey Diagram of Clean Energy Technology Supply Chain



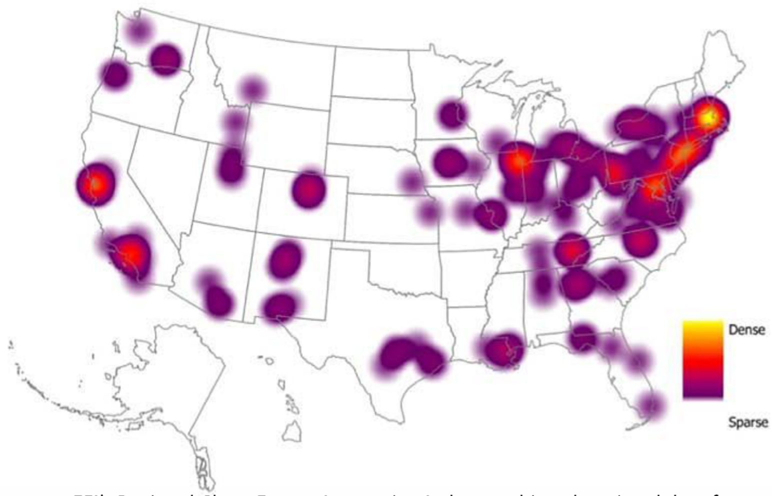
The clean energy technology supply chain is vast and complex but also includes numerous interconnections between raw materials and technologies.
Source: McCall, 2017, Clean Energy Manufacturing Analysis Center

and needs to exploit regional innovation strengths. Nurturing energy innovation ecosystems at a regional scale can be the critical catalyst for aligning the key players, policies and programs among the private sector, universities and governments. Energy resources, expertise and markets vary significantly by region of the country, and many of the issues facing the energy sector can be better managed by strategies tailored to each region's specific needs.

Analysis of national data on energy innovation reveals strong regional clustering. Combining data on the location of Department of Energy (DOE) national laboratories and Energy Innovation Hubs, the DOE-funded Energy Frontier Research Centers, the National Network for Manufacturing Innovation Centers, NASA laboratories and facilities, the top 100 research universities, and the major Federally Funded Research and Development Centers (FFRDCs) into a single heat map shows significant clustering of innovation capabilities (see Figure 12). What the heat map shows is that there is a robust system of innovation enablers in many, but not all, parts of the United States.

Federal policies and programs should be cognizant of these developments and seek to nurture further evolution. The DOE National Laboratories and other federally funded research institutes, working with universities, can play a major role in catalyzing regional energy innovation ecosystems.

Figure 12. EFI's Regional Clean Innovation Index



EFI's Regional Clean Energy Innovation Index combines locational data for energy RD&D resources across the country to analyze the potential benefits to innovation of regional clustering.

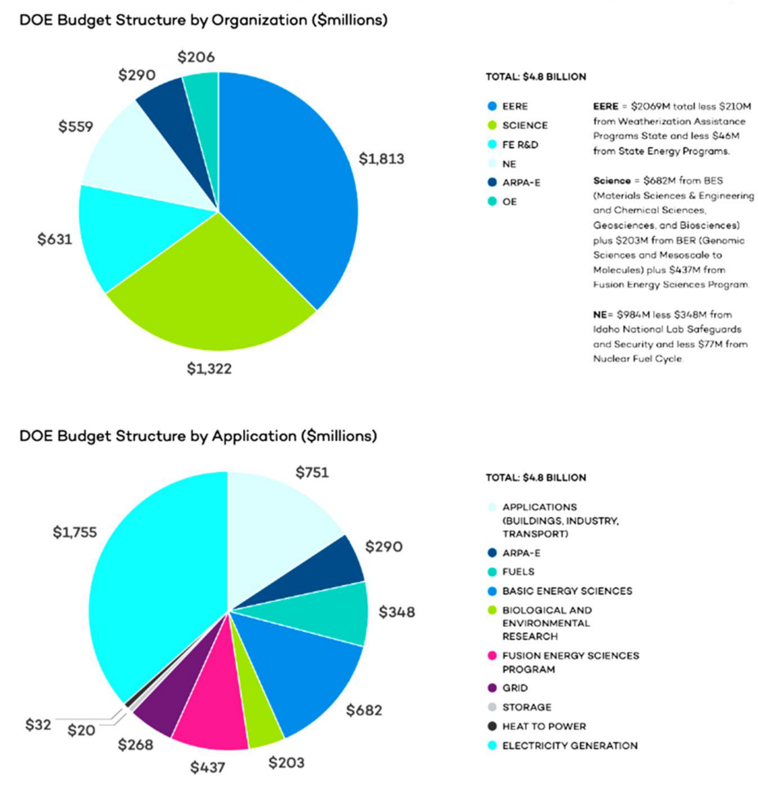
Source: Energy Futures Initiative (EFI), 2017. Compiled using data from Hersch, 2014; Manufacturing USA; National Aeronautics and Space Administration; National Science Foundation; DOE

Finally, the federal energy innovation research portfolio needs to be better planned and managed for performance. The DOE applied energy research programs are currently organized around a fuel centric framework that has its origins in the 1970s, a structure that inherently skews its programs and budgets. It tends to lead to budget allocations by fuel, resulting in gaps and budget distortions, rather than prioritization by innovation potential. The 2019 study *Advancing the Landscape of Energy Innovation*, included an analysis of the FY 2017 DOE budget comparing the budget allocations by organization with a budget allocation by application, shown in Figure 13.

The comparison highlights the relative lack of attention to several key technology areas such as energy storage, grid modernization, heat to power, and hydrogen and other clean fuels. Emerging areas of research needs, such as carbon dioxide removal, had no clear organizational home. The DOE Quadrennial Technology Reviews of 2012 and 2016 represented steps toward better portfolio planning. These efforts should be reinvigorated. In particular, the Conference Report accompanying the Energy and Water Development Appropriations Act for 2021 underscored the need for better multi-year R&D portfolio planning, noting that "The Department is still not in compliance with its statutory requirement to submit

to Congress, at the time that the President's budget is submitted, a future-years energy program that covers the fiscal year of the budget submission and the four succeeding years."

Figure 13. Comparison of DOE Budget Structures by Organization and Application



Source: EFI, 2017. Compiled from DOE Fiscal Year 2018 Budget Documents

The current structure also lacks clear direction for supporting all stages of the innovation process from fundamental research through commercial demonstration. Demonstration projects are an essential element of the innovation process for testing new technologies at scale with full integration of components and sub-systems. The learning by doing achieved through demonstration projects is an

essential two-way street, enabling any necessary fine tuning as technologies enter commercial deployment as well as providing important feedbacks to guide further research priorities. The management of DOE large-scale demonstration projects has a checkered history, leading some critics to propose the proverbial "throw out the baby with the bathwater." Adopting a more rigorous project management guidelines to demonstration projects along with stronger project management oversight, modeled after those applicable to DOE internal construction projects, will be necessary to ensure effective implementation of the new demonstration projects authorized in the Energy Act of 2020.

Conclusion

All of this points to the need for, and ability of the U.S. to sustain its preeminence in clean energy technology innovation but requires far-sighted and sustained action to better align the policies, players and programs that are the key building blocks of our national energy innovation ecosystem. It is my pleasure—once again—to appear before this Committee. I have always found that Members from both sides of the aisle are willing to work together to support U.S. energy innovation, and I would be happy to support your efforts in any way.

Madam Chair, Ranking Member Lucas, members of the Committee, I appreciate the opportunity to testify today on critical clean energy innovation needs. I look forward to your questions.

[i] https://www4.unfccc.int/sites/ndcstaging/Pages/Home.aspx

ENERGY FUTURES INITIATIVE

SUMMARY

- 13th U.S. Secretary of Energy
- Key architect of Paris Agreement and Mission Innovation at COP21
- Co-chair and CEO, Nuclear Threat Initiative
- Founder, MIT Energy Initiative
- Distinguished Fellow at the Emerson Collective

EDUCATION

Boston College
Stanford University

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SOCIAL MEDIA

Ernest J. Moniz

Chief Executive Officer and Founder

Ernest J. Moniz is the CEO of EJM Associates and the Energy Futures Initiative. He served as the thirteenth United States Secretary of Energy from 2013 to January 2017. As Secretary, he advanced energy technology innovation, nuclear security and strategic stability, cutting-edge capabilities for the American scientific research community, and environmental stewardship. He strengthened the Department of Energy (DOE) strategic partnership with its seventeen national laboratories and with the Department of Defense and the broader national security establishment. Specific accomplishments included producing analytically-based energy policy proposals that attracted bipartisan support, implementing legislation, leading an international initiative that placed energy science and technology innovation at the center of the global response to climate change, and negotiating the historic Iran nuclear agreement alongside the Secretary of State. He reorganized a number of DOE program elements, elevated sound project and risk management, and strengthened enterprise-wide management to improve mission outcomes.

Professor Moniz (Pronounced MO-neez) previously served as Under Secretary of Energy from 1997 until January 2001 with science, energy, and nuclear security responsibilities. Before that, he was the Associate Director for Science in the Office of Science and Technology Policy from 1995 to 1997, with responsibility for the physical, life, and social sciences. He was a member of the President's Council of Advisors on Science and Technology as well as the Defense Threat Reduction Advisory Committee from 2009 to 2013. He also served on the Blue Ribbon Commission on America's Nuclear Future that provided advice to the President and the Secretary of Energy, particularly on nuclear waste management.

Professor Moniz was a member of the Massachusetts Institute of Technology faculty from 1973 until 2013 when he was appointed Secretary of Energy. Now, he is the Cecil and Ida Green Professor of Physics and Engineering Systems emeritus at MIT, as well as the Special Advisor to the MIT President. He is co-chairman of the Board of Directors and CEO of the Nuclear Threat Initiative, a non-profit organization that has advanced innovative solutions for securing nuclear materials, building international cooperation for nuclear disarmament and nonproliferation - preventing the spread of disease and reducing radiological threats.

At MIT, Moniz was the Founding Director of the MIT Energy Initiative (MITEI) and Director of the Laboratory for Energy and the Environment. MITEI grew to involve over a quarter of the faculty across the entire Institute, launched new educational programs for energy, and established novel models for industry-faculty engagement that simultaneously provided individualized company research portfolios with a commons approach that lifted the entire energy enterprise.

Moniz was also Head of the MIT Department of Physics during 1991-1995 and 1997 and Director

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SOCIAL MEDIA

Ernest J. Moniz
Chief Executive Officer and Founder

of the Bates Linear Accelerator Center from 1983-1991. His physics research centered the development of a theoretical framework for understanding intermediate energy electron and meson interactions with atomic nuclei. Since 2001, his primary research has focused on energy technology and policy, giving him a leadership role in MIT multidisciplinary technology and policy studies addressing pathways to a low-carbon world (Future of Nuclear Power, of Coal, of Natural Gas and of the Nuclear Fuel Cycle). These studies had significant impact on energy policy and programs nationwide.

Professor Moniz serves on the Board of Directors of both publicly traded and private companies in the energy and security sectors. He also served on the Boards of several non-profit energy industry organizations and, through EJM Associates, is a high-level advisor to several energy-related companies, investment firms, and policy makers.

He received a Bachelor of Science degree summa cum laude in physics from Boston College, a doctorate in theoretical physics from Stanford University, and several honorary doctorates, with some from European universities.

Affiliations
- Non-resident Senior Fellow, Harvard Belfer Center
- Inaugural Distinguished Fellow, Emerson Collective
- Fellow, American Physics Society,
- Fellow, American Association for the Advancement of Science
- Fellow, the Humboldt Foundation
- Fellow American Academy of Arts and Sciences

Awards and Honors
- Award for Excellence in Public Policy and Public Affairs, American Academy of Arts and Sciences (2019)
- Grand Cordon of the Order of the Rising Sun - Japan (2019)
- Richard A. Meserve Public Service Award, Carnegie Science (2018)
- Franklin D. Roosevelt Distinguished Public Service Award (2017)
- Richard E. Neustadt Award, Harvard Kennedy School (2017)
- Charles Percy Award of the Alliance to Save Energy (2016)
- Distinguished Public Service Award, U.S. Department of Defense (2016)
- Distinguished Public Service Award, U.S. Navy (2016)
- Grand Cross of the Order of Prince Henry the Navigator - Portugal (2015)
- The Right Stuff Award of the BlueGreen Alliance Foundation (2014)
- Grand Cross of the Order of Makarios III - Cyprus (2008)
- Seymour Cray HPCC Industry Recognition Award (1998)

Mr. BERA. Should we go to the final witness?

TESTIMONY OF DR. FARNAM JAHANIAN, PRESIDENT, CARNEGIE MELLON UNIVERSITY

Dr. JAHANIAN. I'd be happy to. Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, I am grateful for the opportunity to testify today. My testimony is shaped by my perspective as a university president, my public service at the National Science Foundation, my experiences as a computer scientist and an entrepreneur, and as an immigrant who came to this country at the age of 16.

Throughout this Nation's history, a thriving research and development ecosystem has served as a foundation for broad economic prosperity, national security, and individual and collective wellbeing. Today, we see this ecosystem at a crossroads, shaped by three major trends. The first is the unprecedented scope, scale, and pace of innovation. Major leaps in data-enabled, technology driven research are impacting a wide range of applications and industries, from drug discovery and enhanced telemedicine, to new materials for clean energy, breakthroughs in transportation and manufacturing, and the very essence of scientific discovery itself.

The second is the rise of global competition, as you just heard. The U.S. R&D engine has been the envy of the world for the past half century, and our global competitors are now replicating our model of an innovation-based economy. The need to invest and outinnovate could not be more urgent.

And finally, this moment is defined by a widening opportunity gap and a rising economic inequality. Digital transformation and globalization have contributed to a profound reshaping of our workforce, and persistent structural barriers to access and opportunity are preventing the benefits of our innovation-based economy from being widely shared.

At this critical moment, our national response should rest on four thrusts as outlined in my submitted testimony. Investing in research at the pace of discovery and innovation, winning the global race for talent, committing to a robust research and innovation infrastructure, and finally, expanding the geography of U.S. innovation.

Let me highlight key recommendations in several of these areas.

First, if we're to compete and win, the Nation must urgently increase Federal investment in research to double the current levels for the next several years. To some, the current moment creates an imperative to choose between increased support for curiosity-driven research versus strategic mission-driven initiatives in emerging technologies. This is a false choice. Scientific exploration occurs along a dynamic continuum from foundational discovery to use-inspired research. Breakthroughs from the internet to self-driving cars, to rapid development of MRNA vaccines all stem from support for innovation across this dynamic continuum.

Along with foundational research across all disciplines, we must also invest in use-inspired research motivated by national and societal priorities in healthcare, sustainability, transportation, clean energy, public health, cybersecurity, and much more.

To catalyze mission-driven approaches for these complex challenges, the Nation needs targeted investments in the emerging technologies that have become near ubiquitous in their impact, including artificial intelligence, robotics, advanced manufacturing, materials, biotechnology, quantum computing, and next generation wireless.

Second, the Nation must win the global race for talent and build a broad-based science and technology workforce that leaves no one behind. We must ensure every child and young adult has access to training and digital competency and computational thinking, double the number of graduate students and postdoctoral researchers in science and engineering, and broaden public/private partnerships for human capital development.

Finally, the United States needs now bolder strategies for transitioning discoveries from lab to market. With an intentional focus on expanding the geography of U.S. innovation, our universities and national labs have extraordinary capacity to generate discoveries and innovations that catalyze economic growth and job creation. The Nation must invest in entities adjacent to universities that are capable of facilitating the seamless fusion and transfer of ideas, technologies and skills. The possibilities for creative, innovation-based economic development to support American competitiveness are endless.

I'm grateful to this Committee for the important work that you do, including advancing the *NSF for the Future* legislation. The boldness of your actions is a poignant reminder of the transformative power of science, technology, and innovation to advance our economic prosperity and national security. The education and research community is ready to seize the opportunities that lie ahead.

Thank you again for the opportunity to testify today.

[The prepared statement of Dr. Jahanian follows:]

Testimony of Dr. Farnam Jahanian
President, Carnegie Mellon University

before the

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

April 15, 2021

"Reimagining our Innovation Future"

Chairwoman Johnson, Ranking Member Lucas, and Members of the Committee, I am grateful for the opportunity to testify today. My name is Farnam Jahanian, and I currently serve as president of Carnegie Mellon University (CMU) and had the honor of previously serving as Assistant Director for Computer and Information Science and Engineering at the National Science Foundation.

My testimony will underscore the foundational role that science and engineering continues to play in our nation's prosperity for the past seven decades. It also speaks to the urgency of the current moment. Today, as unprecedented advances drive societal and economic transformation, the United States must double down on our national investments in research and innovation to secure our global competitiveness and address complex societal challenges. While we need the power of large, intentional, and sustained investments in emerging technologies such as artificial intelligence (AI), advanced manufacturing, and quantum computing, we also require investment across the continuum of innovation – from curiosity-driven discovery and use-inspired research, to our national scientific infrastructure and workforce development efforts, and a robust ecosystem for technology transfer.

I. A Nation Dedicated to New Frontiers in Science, Technology, and Innovation

Throughout our nation's history, and especially in the post-World War II era, a thriving research and development (R&D) ecosystem has served as the foundation for broad economic prosperity, national security, and individual and collective well-being. Advancements in science and technology have sparked new businesses and markets, modernized our system of health care, improved life expectancy and quality of life, and created more interconnected society. They created the modern world and placed the United States at the forefront of innovation. This took significant investment and risk-taking to achieve, with the U.S. taxpayer serving as the most important investor in catalyzing our nation's discovery and innovation.

The process of innovation has often been marked by long, unpredictable incubation periods between initial scientific discovery and societal and economic impact, requiring sustained investment at every step of the way. We have seen this in a broad range of technologies and industries, including the Internet, semiconductors,

clean energy, advanced materials, biotechnologies, and genomics, to name a few. While the initial investment is often made by the federal government, the private sector plays a critical role in the R&D continuum to turn federally funded research into commercial impact, with broad economic and societal benefits. For example, consider the rise of autonomous vehicle (AV) technology, which illustrates the powerful impact of curiosity-driven research combined with intentional investment in key technologies.

In tracing the history of AV technology, many choose to start the narrative on March 13, 2004. On that day, 15 vehicles competed to make history in the first-ever Defense Advanced Research Projects Agency (DARPA) Grand Challenge, which was focused on fostering the development of self-driving ground vehicles. The immediate goal: autonomously navigate a 142-mile course that ran across the Mojave Desert, with a longer-term aim to accelerate development of the technological foundations for autonomous vehicles that could ultimately substitute for men and women in hazardous military operations.

That first competition – and subsequent Grand Challenges in this field – incentivized a community of innovators, engineers, programmers and students to try and solve a complex technical problem. But when one considers the knowledge and insight they brought to those early challenges, the rich history of federally-funded foundational research during the previous decades emerges – research that enabled all subsequent innovation in this area. For approximately a quarter of a century – from 1980 to 2003 – university research centers, often funded by or in partnership with federal agencies, undertook fundamental studies into the technologies that underpin autonomous transportation, including early-stage locomotion capabilities, obstacle detection and avoidance, light detection and ranging (LIDAR), radar and computer vision, AI, image processing, omni-directional cameras, and other sensing technologies. These innovations were initially forged by years of investment in curiosity-driven programs across eight different federal agencies including the National Science Foundation (NSF), the Department of Energy (DoE), the National Aeronautics and Space Administration (NASA), the Department of Transportation (DoT), and the Department of Defense (DoD). And those early pioneers were *themselves* building on a national computing infrastructure that had its origins in federal investment, including significant support from NSF and DARPA for computer science departments and university computing centers in the 1960s, 1970s, and 1980s.

The rise in AV technology has had broad national and economic impact, and its growth in the next few decades is expected to soar. A recent joint report from Intel and the research company Strategy Analytics estimates that autonomous car technology could add $2 trillion to the U.S. economy by 2050 and make a global market of $7 trillion accessible to U.S. innovators.[1] The symbiotic relationship between the public and private sectors has contributed to a stunning rise of the autonomous vehicle and robotics industry in Pittsburgh, where major AV companies have attracted billions of dollars of investment in new engineering centers that dot Pittsburgh's Robotics Row as well as test facilities across rural Southwestern Pennsylvania. More than 80 robotics companies are now located in Pittsburgh – many directly spinning out of CMU – and they employ more than 3,000 people.[2] Many of these jobs are located in Pittsburgh neighborhoods that are adjacent to CMU's National Robotics Engineering Center (NREC), our center for use-inspired and translational robotics research. These concentrated geographies – sometimes called innovation districts – have helped to transform the city

[1] "Accelerating the Future: The Economic Impact of the Emerging Passenger Economy," Strategy Analytics report prepared for Intel, June 2017. https://newsroom.intel.com/newsroom/wp-content/uploads/sites/11/2017/05/passenger-economy.pdf
[2] Economic Analysis from Fourth Economy

from one whose economy was driven by steel and mining, to one at the forefront of the modern, global economy.

Time and time again, smart, strategic, early and sustained investment by the federal government has helped to catalyze discovery and innovation that leads to broad societal benefit. This vibrant ecosystem for science and research is precisely what Vannevar Bush, Director of the Office of Scientific Research and Development after World War II, envisioned. He recognized that the interactions of research ideas often multiply their impact and seed new ideas with the potential to lead to unanticipated advances and broad economic impact. In his July 1945 report entitled *The Endless Frontier*, he noted that "[n]ew products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science."[3] His belief in science as a national priority led directly to the formation of the NSF, and ultimately led the United States to further expand its science policy through agencies like DARPA, the National Institutes of Health (NIH) and NASA. It also underpins our response to the current moment.

II. An Inflection Point for the Nation

More than three quarters of a century after the publication of the *Endless Frontier* report, the United States science and engineering enterprise is at an inflection point. Our nation is poised at a remarkable confluence of opportunities and challenges. In particular, three realities are making this moment in time distinctly consequential: (1) a historic acceleration in the pace and scale of technological advances; (2) intense global competition by motivated challengers; and 3) a widening economic opportunity gap that is leaving far too many Americans behind.

Unprecedented Pace and Scale of Discovery and Innovation

We are in the midst of a profound societal and economic transformation that is being catalyzed by rapid advances in digital technologies, by access to unprecedented amounts of data, and by a powerful convergence of cross-disciplinary knowledge, methods and expertise.

The scale, scope and pace of these advances are truly unprecedented in human history. We are not dealing with a singular technology, but rather a set of interrelated breakthroughs that is expanding capabilities on a colossal scale. This dynamic necessitates an approach that fosters cross-disciplinary education and research, and close interaction between technologists and domain experts. The scope of impact is also remarkable, with near ubiquitous deployment that is reaching every sector of our economy and a wide range of occupations. Finally, the pace of innovation is dramatically accelerating, requiring new strategies for integrating foundational research and use-inspired research with more flexible approaches to technology transfer and workforce development. These advances are underpinning our economic prosperity, our national security and are accelerating the pace of discovery in nearly all fields of inquiry.

These cascading advances have re-shaped the culture and conduct of scientific research, with computation and data at the forefront of discovery in ways that were barely imagined twenty-five years ago. Data has become a particularly transformative currency for science, engineering, and education, with practitioners quickly

[3] *Science: The Endless Frontier, A Report to the President* by Vannevar Bush, Director of the Office of Scientific Research and Development, July 1945 (United States Government Printing Office, Washington: 1945)

extracting powerful insights from massive data sets and creating new approaches to drive discovery and decision-making. Combined with the deep integration of the cyber and physical worlds, wireless connectivity at broadband speeds, and seamless access to resources in the cloud, this explosion of data has catalyzed discovery and innovation.

The growing impact of data has also amplified the power of artificial intelligence and machine learning – which collectively represents one of most significant intellectual developments of our time. While the deployment of AI has ethical, policy and privacy implications that humanity must consider, AI and other computational technologies can powerfully augment our cognitive and even physical capabilities – in speech recognition and language translation, computer vision, assistive technologies, Internet search engines, and educational outcomes. Stemming from a strong legacy of federal investments in both basic and applied research, the total economic and societal impact of artificial intelligence is vast and on the edge of exponential growth. It is estimated that, by 2030, the global market size for AI will have grown to nearly $1.4 trillion.[3] AI and machine learning are also combining with other emerging fields to advance new frontiers in healthcare, smart transportation, advanced manufacturing, climate, clean energy, agriculture, and education, among others.

A convergence of knowledge, methods, and expertise from different disciplines continues to catalyze discovery and innovation and help solve complex societal problems facing humanity. For example, the successful development of novel messenger RNA-based (mRNA-based) vaccines – now available for the SARS-CoV-2 virus – was only possible due to convergent developments in basic research over the past decade, much of it funded by the NIH, combined with the ability to engineer proteins that mitigate the virus. More recently, an NSF-funded team of multidisciplinary researchers used a "computational microscope," linking high-performance computing with artificial intelligence, to develop the first full-scale model of the coronavirus spike protein itself. They later simulated 305 million atoms showing the fine details of how the spike protein moves, opens and contacts a healthy human cell. Their work has paved the way for drug and vaccine development.[4]

In an increasingly knowledge-based global economy, scientific discoveries and technological innovations must lie at the core of our response to national priorities and societal challenges – not just in medicine and healthcare but in sustainability, access to clean air and water, food security, transportation, clean energy, public health and safety, cybersecurity, and national defense.

<u>Global Competition</u>

The U.S. R&D engine had been the envy of the world for the last half century, and we should not be surprised that our global partners and competitors are replicating our extraordinarily successful model of an innovation-based economy.

In 1960, the United States dominated research and development (R&D), accounting for a 69 percent share of global R&D investment.[4] Our investments put us squarely in the driver's seat when it came to scientific discovery and technological innovation. In more recent years, with the democratization of knowledge and

[3] HR&A projections based on data from Allied Market Research, Grand View Research, Fortune Business Insights, and Tractica.
[4] First ACM Gordon Bell Special Prize for High Performance Computing-Based COVID-19 Research Awarded, November 19, 2020. https://www.acm.org/media-center/2020/november/gordon-bell-special-prize-covid-research-2020
[4] Competing in the Next Economy: The New Age of Innovation, Council on Competitiveness, pg. 13-14

broadening access to emerging technologies, other nations have increased their R&D investments, while the U.S. global share of R&D investments has dropped to just 29 percent in 2020.[5]

A nation's R&D intensity, expressed as R&D expenditures as a percentage of GDP, provides another gauge of national R&D performance. In this particular measure, the U.S. position globally again has lagged. The United States' R&D investment as a percent of GDP now ranks 10th in the world, behind major global competitors such as Taiwan, Japan, Germany, and South Korea, which rank at the top in this metric.[6] With the nation's *federal* spending as a percent of GDP dropping from more than 2 percent at the end of the 1960s to just slightly less than 0.7 percent currently, we have ceded considerable ground in the race to discover, innovate and create the fair, equitable and productive economies of the future.

Of all our global competitors, China is particularly focused on investing at scale to replicate the U.S. model of science- and technology-based growth and is rapidly closing in on the United States in measures such as gross R&D spending, funding for basic research, patents granted, and scientists and engineers employed. China now awards more bachelor's degrees in science and engineering than the United States, the European Union and Japan combined.[7] In recent years, R&D investment has soared by an average of 18 percent annually in China, whereas even with growing bipartisan support, U.S. federal spending rose by just over 4 percent each year.[8]

The United States became a world power due to our fervent belief in the power of American ingenuity. Now, we must double down on what we do best: leading the world in innovation, creativity and finding solutions to society's most pressing challenges. For decades, our research enterprise has been successful because we have competed globally not in the hope that others will lose, but in the belief that when we win, the world wins.

As we navigate the delicate balance between open research and national security, the nation must remain clear-eyed and alert to the threat of foreign influence in the form of intellectual property theft, cyber-attacks, espionage and other broad-scale, state-sponsored efforts. These are direct threats to our national security and economic prosperity, and the U.S. must be diligent in taking action in such cases but must not go so far as to retreat from global engagement or change the way research is conducted. We must not cripple the engine that has delivered fruitful economic and societal benefits. In this most disruptive age, we will win by out-investing and out-innovating.

A Widening Opportunity Gap

As we consider this inflection point for our nation, we must also acknowledge recent evidence that large segments of our population in both rural and urban communities are being left behind in this new economy. A recent study by Brookings found that 90 percent of technology related job growth has taken place in just five coastal metro regions.[9] Economic inequality is on the rise, not only because of digital transformation and globalization, but also due to persistent structural barriers to access and opportunity. The COVID-19 pandemic

[5] A Snapshot of U.S. R&D Competitiveness: 2020 Update, Report from the American Association for the Advancement of Science (AAAS), October 22, 2020. https://www.aaas.org/news/snapshot-us-rd-competitiveness-2020-update
[6] A Snapshot of U.S. R&D Competitiveness: 2020 Update, Report from the American Association for the Advancement of Science (AAAS), October 22, 2020. https://www.aaas.org/news/snapshot-us-rd-competitiveness-2020-update
[7] National Science Board, Science and Engineering Indicators 2018, NSB-2018-1 (National Science Foundation), 2-47–2-60.
[8] "The Rise of China in Science and Engineering," National Science Board, Science and Engineering Indicators 2018 (National Science Foundation). https://www.nsf.gov/nsb/sei/one-pagers/China-2018.pdf
[9] Robert D. Atkinson, Mark Muro, and Jacob Whiton, "The case for growth centers: How to spread tech innovation across America," Brookings Institution, December 9, 2019. https://www.brookings.edu/research/growth-centers-how-to-spread-tech-innovation-across-america.

and the subsequent economic downturn have only amplified these inequalities, and made the issues surrounding access and opportunity more urgent.

Although the current gaps in opportunity and access are tied to a variety of factors, it is undeniable that the rapid pace of technological change has contributed to a profound re-shaping of the workforce. As technologies enhance and, in some cases, outpace, human capabilities, entire industries are expanding and contracting, and the skills needed to keep up in almost any job are increasingly churning at a faster rate.

As the president of a research university, I believe innovations in education will be key to staying ahead of the fast-moving current. Our system of education must deliver continuous training in the uniquely human skills that will only increase in relevance as automation matures – such as communication, problem-solving, collaboration, and critical and ethical thinking – but we must also create a national initiative to increase STEM education. We are seeing an undeniable and growing reliance on science and technology as drivers of new jobs. In fact, the Department of Labor estimates that science, technology, engineering, and mathematics (STEM) occupations are projected to grow more than two times faster than the total for all occupations in the next decade. But, according to the Smithsonian Science Education Center, about 2.4 million STEM jobs went unfilled in the U.S in 2018, and it is feared that we are not equipped to provide the base of talent to meet this rising need.[10] Developing human capital is especially important in areas that are identified as critical, emerging technologies. The demand for AI talent, for example, has grown by 74 percent annually in the past four years, and we will need to retrain or upskill up to an estimated 11 million workers in the next three years.[11]

Winning the race for talent demands more aggressive strategies to bring greater diversity to our STEM talent base and address long-standing barriers to broadening participation. The Smithsonian Science Education Center report also found that just 2.2 percent of Latinos, 2.7 percent of African Americans, and 3.3 percent of Native Americans and Alaska Natives have earned a university degree in STEM fields[12]. If not addressed, lack of sustained pathways will hamper U.S. efforts to develop the strong and diverse domestic STEM workforce that is so critical to the growth of our innovation-based economy.

Given the rapid pace of change, learning must be a lifelong endeavor, with continuing education serving as a tool for people of all ages and backgrounds. It is increasingly important for higher education to work closely with partners in the public and private sector on workforce development, including apprenticeships and re-skilling. Without significant public and private investments in workforce development and re-skilling initiatives, the nation may inadvertently disenfranchise parts of our population from gaining access to opportunity. We must be very intentional in building an innovation economy that engages everyone and that works for everyone – the nation's rural and suburban communities as well as its cities. If we succeed, the United States will fully realize the power of science and technology as a force for shared prosperity.

III. An Agenda for Action

These economic and societal transformations demand that we think and act anew. Bold steps are needed to ensure that the United States remains a leader in scientific discovery and to activate America's defining entrepreneurial spirit in translating discoveries into solutions, products and services that benefit society.

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[10] Smithsonian Science Education Center STEM initiative, https://ssec.si.edu/stem-imperative
[11] The Perils of Complacency: America at a Tipping Point in Science & Engineering, American Academy of Arts and Science, September 2020, pg. 16
[12] Smithsonian Science Education Center STEM initiative, https://ssec.si.edu/stem-imperative

The pandemic has demonstrated how the power of science can mobilize rapidly to meet urgent societal needs. In many respects, it was an illustration of American science and innovation at its best. Yet the pandemic has also shined a light on the need for our science and innovation ecosystem, and the policies that support it, to be much more intentional in generating economic opportunities and promoting a high quality of life in all communities in our nation. The reality of the nation's growing economic divide, as much as increased international competition, should define a "Sputnik" moment for our times.

The nation must now come together around a shared national vision for science and innovation: a vision that mobilizes to meet new challenges while renewing and reinvigorating the promise of discovery and innovation to expand economic and social mobility. I believe this call-to-action should rest on four thrusts: (1) Investing in Research at the Pace of Discovery and Innovation; (2) Winning the Global Race for Talent; (3) Committing to a Robust Research and Innovation Infrastructure; and (4) Expanding the Geography of U.S. Innovation. The ideas outlined below are offered as potential building blocks of such a vision.

1. Invest in Research at the Pace of Discovery and Innovation

America's total national (public and private) investment in research and development as a fraction of our GDP has remained stagnant at between 2.4 and 2.7 percent for nearly half a century.[13] And as noted earlier in this testimony, if you look at the overall federal investment in research and development, it actually declined steadily during that period – to around 0.7 percent of our GDP, well below previous levels. Furthermore, federal funding specific to research – both basic and applied – has remained flat, hovering around 0.4 percent of our GDP for about half a century. The nation must urgently increase federal investments in research to double the current levels over the next several years; this increase is needed to invest in the "big bets" that will drive our global leadership and enable the science and technology breakthroughs needed to address urgent societal challenges. Increased investment is also needed at this time to address the impact research disruptions stemming from the pandemic.[14]

Yet, we cannot merely spend our way to improved competitiveness. The accelerating pace of innovation also necessitates a fundamental re-imagining of the American research enterprise. To some, the current moment creates an imperative to choose between increased support for curiosity-driven research and strategic, mission-driven initiatives in emerging technologies. This is a false choice. Scientific exploration occurs along a dynamic continuum — from foundational discovery to use-inspired research. A historic strength of the American innovation ecosystem has been the role of the federal government in de-risking investment at both ends of this continuum. In areas ranging from nanotechnology, battery storage and the internet to genomic medicine and drug discovery, fostering interaction between fundamental research and use-focused applications has transformed industries, created new ones and helped address previously intractable societal challenges. The failure of public investment to keep pace with the growing role of innovation in catalyzing economic growth is a threat to our future.

The United States must invest in, and re-energize, the environment for foundational research across all disciplines. This requires investments to pursue bold ideas that may seem, at first, to have little immediate

[13] The Perils of Complacency: America at a Tipping Point in Science & Engineering, American Academy of Arts and Science, September 2020, pg. 13
[14] See the Research Investment to Spark the Economy (RISE) Act. https://www.congress.gov/bill/117th-congress/house-bill/869

application to products or specific industries, yet hold long-term potential for transformational breakthroughs. Such investments should include funding for early career awards as well as support for multi-disciplinary and multi-investigator research.

Revitalizing our approach also requires a commitment to use-inspired research that is motivated by complex societal challenges, including realizing clean air and water, advancing public safety, addressing inequality and creating a more resilient and opportunity-rich economy. Specifically, to create innovative solutions that meet our national priorities, the nation must urgently invest in emerging technologies that have become near ubiquitous in their impact over the past decade, including AI, autonomy and robotics, advanced manufacturing, materials science, biotechnology, quantum computing and next-generation wireless. Breakthroughs in these high-impact research areas are critical to addressing societal challenges and hold enormous potential to create new industries and transform existing sectors – from agriculture and manufacturing, to healthcare and transportation, and beyond.

To extract the most value from these technologies over the long run, especially given the accelerating pace of innovation, it is vital that our investments in these areas include research across the continuum – including both foundational as well as use-inspired – and that we also embed a focus on ethics, privacy and workforce impacts at all levels of science education and research.

As recognized by Congress and the administration, this interplay between foundational discovery and use-inspired research to meet major societal challenges and enhance our global competitiveness demands the creation of a new directorate within the NSF. Working synergistically across the foundation, this directorate would serve as the hub for mission-driven innovations and solutions that may be enabled by powerful, emerging technologies. The foundation should be given flexibility to structure this directorate in a way that would leverage NSF's strengths and its relationships with other agencies and the private sector, and allow it to adapt to evolving national priorities and technologies of the future.

The directorate must have the capability to support research at scale across the continuum – from breakthrough discovery to use-inspired development, prototyping and deployment. This will require investments in center-scale initiatives and new models for public-private and multi-institutional collaborations capable of engaging the best researchers across the nation with the frontline end users of technology. To accelerate technology transition, the directorate should also support work to align education and re-skilling initiatives with research efforts. The directorate should also align its technology transfer initiatives with a goal of expanding the geography of innovation.

Finally, to pull together our collective efforts to increase research funding and restructure key science programs, the nation should also commit to establish a National Grand-Challenges Initiative. One of the historic strengths of American science has been its capacity to spark the national imagination and mobilize an all-of-nation commitment toward bold goals. These kinds of "grand challenges" go beyond targeted research questions; they speak to ultimate, high-stakes goals that are transformative in their impact, scale and ability to seed major breakthroughs. While grounded in technical pursuits, Grand Challenges energize individuals and entrepreneurs from all walks of life, and from both public and private sector organizations. Grand Challenges can also accelerate the transition to commercial development, lead to next-generation training programs and help to expand the geography of innovation to encompass communities across the nation.

2. Win the Global Race for Talent

The potential economic and societal impact of discovery and innovation will not fully be realized without also winning the global race for talent. Attracting the world's top talent is crucial to capitalizing on the investments we make in research to achieve scientific discoveries and technological innovations.

The nation must match its commitment to re-energizing the research enterprise with bold new initiatives in STEM education across preK-12, college, graduate and post-graduate education as well as in workforce training and re-skilling. A central focus of this effort must be increasing the diversity of the American science and technology workforce, simultaneously ensuring that no region of the nation is without high-quality STEM education for its children and young people. This investment must be an essential component of a national strategy to increase the nation's STEM workforce, broaden pathways to careers and create more opportunities to participate fully in today's innovation economy.

As digital innovation is transforming every sector of our economy and facet of our society, it is essential that every child has access to high-quality programs aimed at building digital competency and encouraging computational thinking. (NSF's CSforALL program, which supports rigorous K-12 computer science education across the nation, is a promising model upon which to build.) The United States must redouble its commitment to a public-private partnership aimed at making computer science education available to every middle and high school student in America. Creative community-based initiatives can leverage this investment to expand adult retraining and re-skilling initiatives as well.

Building on these initiatives in STEM, we should also commit to doubling the number of graduate students and post-doctoral researchers in science and engineering. Such an effort should not only focus on an expansion of the number of fellowships; it should also re-envision graduate education to ensure that the public or private sector leaders of tomorrow are prepared for the ever-accelerating pace of innovation and the societal and economic challenges they will be summoned to address. Special attention should also be paid to pathways for the industry and government workforce, with fellowships available so they can return to school for advanced degrees.

A new National Scholarships for Service Initiative can inspire a much closer connection between Americans and our national science mission and embody an all-of-nation commitment to advancing innovation. Such an initiative could have two components – one would provide training for those not headed to traditional college through apprenticeships or "stackable" micro-credit/nano-degree vocational programs, while another would extend financial support to those individuals headed to a four-year college to study high-demand disciplines. In exchange for training or aid, participants in the program would contribute to the nation through local, state or national service in an occupation related to the learned skill, with private sector employment in rural or underserved areas also qualifying as service. In order for this public-private partnership to be successful, the federal government should expand its engagement with vocational colleges, industry and local communities to incentivize re-skilling and capacity building, and drive talent into high-demand fields. Such a program could ignite new models of collaboration across the educational continuum and support economic development initiatives in regions across the country. The NSF's Scholarship For Service (SFS) program, which is focused on developing a superior cybersecurity workforce, is an example of a successful model. The SFS program recruits and trains the next generation of information technology professionals to meet the needs of the cybersecurity mission across federal, state and local governments.

Each of these measures to build new pathways to the innovation economy would be strengthened by securing America's standing as a magnet for global talent – and recruiting the world's top minds. One-third of U.S. Ph.D. STEM graduates are not U.S. citizens or permanent residents, and 28 percent of U.S. STEM faculty were born overseas, as were over half of U.S.-trained science and education postdoctoral workers.[15] The ability to attract the best and brightest to innovate and work alongside Americans has been vital to American innovation since Thomas Edison started his lab in Menlo Park and Major General Groves assembled talent for the Manhattan Project. That proud tradition continues today, and as a president of a major research university, I have witnessed firsthand the contributions that international students make to our research community. Many of these scholars go on to become remarkable innovators; for example, nearly half of U.S. Fortune 500 companies were founded by immigrants or children of immigrants.[16] Considering that 80 percent of international students who come to the U.S. to study in critical fields wish to stay in America,[17] I believe facilitating the ability of foreign students who earn advanced degrees to remain in the United States would be a powerful contribution to America's talent development and innovation capacity.

3. Commit to a Robust Research and Innovation Infrastructure

Accelerating research and building a vibrant science and technical workforce also depends on a robust national research infrastructure.

Research infrastructure investments are essential to fostering multi-disciplinary collaborations and early-stage partnerships with industry. Such infrastructure does not just include hardware and physical equipment; it encompasses software, services, tool development and operational support.

While facilities and instrumentation such as highly powerful telescopes, photonic light sources and particle accelerators have always been vital to our progress in basic scientific investigation, a 21st-century environment must also support research and discovery across the spectrum of digital innovation. This includes targeted investments in the digital research infrastructure capabilities needed to support advances in AI, data analytics, robotics, edge computing and microelectronics. Vast research cloud computing assets, sensor networks and testbeds that facilitate big data and system modeling and simulation, and living laboratories that allow for piloting research-based solutions in practical settings are *all* essential for demonstrating technologies and experimenting on solutions *at scale.*

Given that large-scale digital innovation is increasingly dependent upon the ability to capture, process and manage large amounts of information, a National Data Initiative is a key linchpin in a competitive national research infrastructure strategy. Such an initiative would provide science, engineering and education with a comprehensive data infrastructure to enable the capture, management, curation, analysis, interpretation, archiving and sharing of data at unprecedented scale, parallelism and complexity in a manner that will stimulate discovery in nearly all areas of inquiry.

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[15] National Science Board, Science and Engineering Indicators 2018, 2-61–2-85. https://nsf.gov/statistics/2018/nsb20181/report/sections/higher-education-in-science-and-engineering/graduate-education-enrollment-and-degrees-in-the-united-states.
[16] Ian Hathaway, "Almost Half of Fortune 500 Companies Were Founded by American Immigrants or Their Children," The Avenue, December 4, 2017, Brookings Institution.
[17] Remco Zwetsloot, Roxanne Heston, and Zachary Arnold, "Strengthening the U.S. AI Workforce: A Policy and Research Agenda," Center for Security and Emerging Technology at iii, Sept. 2019. https://cset.georgetown.edu/wp-content/uploads/CSET_U.S._AI_Workforce.pdf.

Finally, this national infrastructure investment must be aligned with accelerated research and deployment of next-generation broadband capability. Innovations in a broad range of applications and industries – ranging from transportation, energy and smart cities to environmental sciences and health care – all depend upon convergence with advances in connectivity. High-speed broadband and access to advanced computing and data infrastructure are vital to bridging the divide between discovery and deployment for a host of innovations and in closing the "geography gap" that prevents the entire country from contributing to our national prosperity and competitiveness.

Expanding the nation's research infrastructure will diversify and democratize American science as research infrastructure "hubs" can play a critical role in supporting STEM programs and providing a gateway to thriving regional innovation ecosystems.

This committee has long recognized the power of investments in infrastructure to support discovery and innovation. It is now time to build upon this leadership and significantly expand our investment in research infrastructure initiatives.

4. Expand the Geography of U.S. Innovation

To compete in an increasingly global marketplace and expand the power of science and innovation to address major societal challenges, the U.S. needs new, bolder strategies for transitioning discoveries from the lab to the market, with a focus on expanding the geography of U.S. innovation. The nation must facilitate the development and deployment of innovations emerging from our universities and national labs faster and at a much greater scale than we are currently realizing.

Policies that nurture a re-energized national R&D environment and foster a culture supportive of technology transfer constitute a pivotal starting point. We can think of this national environment as consisting of a set of fundamental building blocks that come together to catalyze innovation. These building blocks include:

- Government investments in research and education;
- A vibrant and diverse base of scientists and engineers in a flexible talent-rich labor market;
- A private sector catalyzed by the American entrepreneurial spirit;
- Public-private partnerships that spur productive entrepreneurship and enhance both skill development and innovative supply chains; and
- A strategic alignment of education, economic and community development and infrastructure initiatives with innovation strategies.

Federal agencies have a unique role in cultivating these building blocks and nurturing an environment conducive to the rapid transition of technology from lab to market. This can include funding that can enable promising research projects to more easily move to a prototype development stage and testbeds to model the early-stage deployment of technologies. The nation also has the opportunity to scale its existing suite of programs focused on technology transfer.[18] These and other measures can incentivize earlier engagement with both industry and regional innovation ecosystems, accelerating the path from research to discovery.

[18] These existing programs include ones led or initiated by the National Science Foundation, including Innovation Corps (I-Corps), the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, as well as the Partnerships for Innovation (PFI) program.

Furthermore, the nation must commit to expand significantly the U.S. geography of innovation, anchored by our universities and national labs. U.S. academic institutions and research labs have an extraordinary concentration of intellectual capital and capacity to generate ideas, discoveries and innovations that can catalyze economic growth and job creation. For example, there are more than 200 institutions, distributed across rural, urban and suburban America, with significant research capabilities – each with at least $50 million in R&D expenditures annually.[19] The strengths of these institutions may vary, but each institution can offer scientific and engineering assets to help its surrounding region become part of the innovation economy. There is tremendous potential to launch programs that prompt colleges and universities to intentionally partner with their surrounding communities for regional economic development, to motivate research-based solutions to societal challenges, and to enhance the engagement in science and research by a broader cross section of our country. To broaden access to the innovation economy, this collaboration should consider participation by community-based partners, including labor organizations. Furthermore, closer collaboration among universities and colleges within regions and across the nation, especially greater linkages between diverse urban and rural institutions, is an important consideration as we realize this vision.

To complement university-centered efforts, the nation must also invest in entities "adjacent" to universities in the innovation ecosystem that are capable of facilitating hand-offs and the seamless transfer of technology and skills. This effort may require the development of entirely new models of adjacent, community-based innovation support organizations that are driven by a mission to foster a more inclusive technology economy.

It is important to note that a vibrant ecosystem does not measure its success merely by commercial terms and metrics. The transition of technologies and innovations to reduce food insecurity, reduce transit and mobility deserts or improve prenatal care are all examples of strategic objectives for regional innovation.

While attention is often focused on the more visible elements of local innovation ecosystems such as incubators, an important step is to design flexible policies that create the context and conditions for innovation. For example, faculty leave and tenure and promotion policies that support the flow of talent between the university and industry can help facilitate an environment conducive to innovation. This fusion of people and ideas underpins the productive interplay of federally funded university research, privately funded industrial research and entrepreneurial companies founded by people who often move back and forth between universities and companies. Entrepreneurship training for students, faculty and staff, combined with streamlined and flexible intellectual property licensing approaches, can also help define the conditions for innovation. Each of these key policies can be activated by higher education institutions embracing regional economic development as a core mission. The diversity of American institutions of higher education will spark a wide array of strategies. Many institutions have developed research excellence capable of growing startups and generating new industry clusters in their regions; there are some that are best suited to support existing industry through the transfer of knowledge or technology; and others can accelerate the development of new skills throughout the workforce.

These efforts are limited only by our imagination. Just as universities must continue to consider the societal implications of research, institutions charged with job creation and economic growth must now fully embrace the role of science in shared prosperity. The possibilities for creative, innovation-based economic development

[19] Higher Education Research and Development (HERD) Report for Fiscal Year 2019, National Science Foundation, January 29, 2021. https://ncses.nsf.gov/pubs/nsf21314

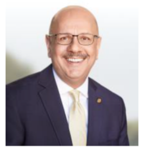
partnerships to support American competitiveness are endless – ranging from pre-competitive, shared, deep bench laboratories to robust and tailored technology entrepreneurship support programming.

IV. Conclusion

Despite the significant challenges before us, it is an inspiring time to be envisioning the future of U.S. leadership in science and technology. The bipartisan proposals emerging in this Congress and from the administration reflect a shared sense of urgency to invest in our nation's competitiveness at a scale and scope not seen since the space race of the 1960s. I wish to acknowledge this committee's bold vison, including the introduction of the National Science Foundation for the Future Act, which would significantly expand funding for the NSF and create a more strategic focus on translational, mission research while also supporting bold initiatives across the entire education and research continuum.

With these investments come significant responsibilities for the science and technology community. Federal agencies, national labs, research universities and our partners must not only continue to be effective stewards of public resources but must also push the envelope in exploring and creating new fields of discovery; forge partnerships across the landscape, including with local communities, private industry and foundations; leverage science and technology to drive competitiveness and job creation; and focus on including people of all backgrounds in these efforts. I know I speak for my colleagues at Carnegie Mellon University and many others across the country when I say our community is determined to rise to the occasion.

Once again, thank you for giving me the opportunity to testify before this committee.



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Farnam Jahanian is the 10th president of Carnegie Mellon University, where he previously served as provost and chief academic officer as well as vice president for research.

A nationally recognized computer scientist, entrepreneur, public servant and higher education leader, Jahanian has extensive leadership and administrative expertise, not only in advancing research and education within and across disciplines, but also in translating research into technologies and practices that benefit society.

Jahanian first joined CMU as vice president for research in 2014, where he was responsible for nurturing excellence in research, scholarship and creative activities. From May 2015 to June 2017, Jahanian served as the university's provost and chief academic officer, with broad responsibility for leading CMU's schools, colleges, institutes and campuses and engaging in long-range institutional and academic planning and implementation.

Jahanian holds faculty appointments in the School of Computer Science, the College of Engineering and the H. John Heinz III College of Information Systems and Public Policy at Carnegie Mellon University.

Prior to coming to CMU, Jahanian led the National Science Foundation Directorate for Computer and Information Science and Engineering (CISE) from 2011 to 2014, where he guided a budget of almost $900 million to advance scientific discovery and engineering innovation through its support of fundamental research. During his tenure at NSF, he also served as co-chair of the Networking and Information Technology Research and Development Subcommittee of the National Science and Technology Council Committee on Technology, facilitating the coordination of networking and information technology research and development efforts across Federal agencies.

Previously, Jahanian spent 21 years at the University of Michigan as the Edward S. Davidson Collegiate Professor. He was director of their Software Systems Laboratory from 1997 to 2000 and served as chair of the university's Computer Science and Engineering department from 2007 to 2011.

Jahanian has been an active advocate for how basic research can be uniquely central to an innovation ecosystem that drives global competitiveness and addresses national priorities. His highly influential research on Internet infrastructure security formed the basis for the Internet security company Arbor Networks, which he co-founded in 2001 and served as chair until its acquisition in 2010.

Jahanian serves as chair of the National Research Council's Computer Science and Telecommunications Board (CSTB), sits on the executive committee of the U.S. Council on Competitiveness, and is a trustee of the Dietrich Foundation. He has also been a board member of the Computing Research Association (CRA), the National Center for Women and Information Technology (NCWIT), and the Allegheny Conference on Community Development, among others.

Jahanian is also active with the World Economic Forum, serving as vice chair of the Global University Leaders Forum (GULF) and as a member of the Global Network Advisory Board for WEF's Centre for the Fourth Industrial Revolution (C4IR). He also serves on C4IR's Internet of Things Council.

Jahanian holds a Ph.D. in computer science from the University of Texas at Austin. He is a fellow of the Association for Computing Machinery, the Institute of Electrical and Electronic Engineers and the American Association for the Advancement of Science.

Ms. STEVENS [presiding]. Great. Thank you so much to our speakers, and as Vice Chair of the Committee, as our Chairwoman proceeds to address her technological issues, I will take over as chair.

We want to thank you all for wonderful testimony, and what we'll do right now is move into the first five minutes of questions. The chair will recognize herself for questions, and then pass it over to the Ranking Member.

So, certainly the breadth of topics and needs that all of you discussed are quite pertinent, and in particular, Secretary Moniz, you had mentioned that the need to not just focus on R&D, but to look at technology transfer applications. And you as well, Dr. Arnold, also touched on that.

But I'd like to get a little more specific. As you mentioned, Dr. Moniz, we can't get this—we don't want to necessarily house all the technology transfer at the NSF, in part because it's early stage, original research applications, and you briefly mentioned DOE. But could you get a little bit more specific about where we might see this mature is the DOD an avenue or at the acceleration of SBIR (Small Business Innovation Research) awards or other public/private partnerships that we should be pursuing? And you can feel free to chime in as well, Dr. Arnold.

Mr. MONIZ. Yes, Congresswoman, I think these are very important issues that you've highlighted.

Let me first kind of reiterate, my view at least is that what we need is not to look in the same way that several of my colleagues have emphasized that there is a kind of continuum across the innovation spectrum. What we need to do is to match that to what I believe is the structure of our very successful—in need of some juicing up—but very successful R&D enterprise across the multiple agencies, with NSF having a very, very broad remit across the entire science spectrum, and other agencies being mission agencies with narrower focus and complimentary roles. It's maintaining the complementarity which is critical.

But as I said, I could see easily NSF having a major lead in leading use-inspired fundamental research. And as I said in the DOE example, once you're into use-inspired fundamental research, you will see spillovers into commercialization. That's the stage at which then that initiatives like SBIR can be extremely successful. I mean, I think we all know of so many examples of SBIR that has helped small companies grow up to the next stage going forward.

And in doing that, I would like to emphasize something that Farnam said, and I said in my testimony as well. In terms of regional innovation systems, we really need to get regional pushes on innovation, and that includes—if you look in my testimony, the written testimony, the heat map of innovation institutions, we've got some blank spaces there, and we need to take advantage of all of our talent in this country, and use that also as a criterion for going from use-inspired research all the way to commercialization.

Ms. STEVENS. Thank you so much.

Dr. Arnold, did you want to chime in there at all? And specifically honing in on a few things that you said that, you know, I love what you were talking about—different topic, but portable fellowships, which I think gets us there too a little bit.

Dr. ARNOLD. Oh, well I'm all for portable fellowships because who does the future belong to? It's those students, and they're smarter than you might think about knowing what the future will be.

But I also want to say that I have received SBIR grants and STTR (Small Business Technology Transfer) grants that are critical for taking things out of the basic research laboratory and moving them at least to the next stage. And it's those young people who often start the companies that benefit from those SBIR grants, so that's a wonderful mechanism, and it's also a very high-quality mechanism. Those are hard to get, and they're very competitive, and I think could easily increase in number and be very beneficial.

Ms. STEVENS. Thank you. Great. Thank you all, and I've got about 30 seconds left, so I'll just reclaim the time. Because in part, even though I'm Vice Chair, right, it's still—I was going to be three in the ranking, so I do want to be respectful of my colleagues and recognize our Ranking Member, Mr. Lucas, for five minutes of questions. Thank you so much, Mr. Lucas.

Mr. LUCAS. Thank you, Vice Chair, and I address my question to the entire panel.

The *Securing American Leadership in Science and Technology Act, SALSTA* as I like to call it, which I introduced last month directs the development of a national science and technology strategy and a quadrennial review, like the process that DOD undertakes for national security.

Can each of you comment on what you would like to see in a process for a whole government strategy for S&T, and how that might benefit American competitiveness? Whoever would care to go first.

Mr. AUGUSTINE. Well, I'll be happy to start, if I may.

I think your question touches on a very important aspect of the issue we're addressing. One of the problems today is we really have no R&D strategy or R&D plan. We also fund our R&D efforts on a yearly basis, and R&D just doesn't work on an annual cycle.

Furthermore, I'm not aware of any successful corporation in America that doesn't have a capital budget. The Federal Government has no capital budget, not in R&D or anywhere else. I think one of the very first steps will be to put together planning that includes emphasis on the transition from the laboratory to the field. We lose a lot of our edge in that transition period.

I will be brief so that my colleagues can speak. I'll turn it over to them.

Mr. LUCAS. Absolutely. Doctor, Doctor?

Dr. JAHANIAN. I'll be happy to chime in next.

If you step back and look at our R&D ecosystem, which candidly is the envy of the rest of the world, the investment that we've made in this country over the last 75 years has not only enhanced our global competitiveness, but very, very bluntly, has enabled so much in this country in terms of the prosperity of our Nation and national security.

But the entire R&D ecosystem not only has the government investment, but it also has to be catalyzed by private sector. You need to have public/private partnerships that spur, essentially, productive entrepreneurship and enhance both skilled development

and innovative supply chain of ideas. You also need to have strategic alignment of education, economic and community development, as well as infrastructure initiatives.

So, any kind of a decadal survey or assessment of this would really have to look at the entire R&D enterprise of the country. Clearly, the government has a huge, huge role to play in this without any doubts. Our agencies across the country, whether it's NSF, NASA, DOD, and so on, and Department of Energy, they have a massive role in terms of shifting and prioritizing our priorities in this country.

But I think we're going to have to bring the private sector into the picture. We're going to have to look at very creative public/private partnerships to be able to advance not only scientific discovery and innovation, but also win the global race for talent, and furthermore, transition effectively what we discover in our labs to market, hopefully creating new industries, products, and services, and beyond.

Mr. LUCAS. Anyone else care to offer some input on that?

Mr. MONIZ. May I add, Mr. Ranking Member?

Mr. LUCAS. Absolutely.

Mr. MONIZ. Let me tee off just from one of the elements that you introduced, the quadrennial review of DOD. I will note that when I was secretary, we initiated a quadrennial energy review, which had the idea of looking at whole of government and looking at an extended period of time, like a 5-year horizon, which was very important. And I might say, that seemed to strike a chord because we had—and you know, in what was a difficult political environment, we had 21 recommendations from that review passed into law by the Congress. So—because I think that leads to a, you know, completely nonpartisan approach to meeting these needs.

So, today, just as one example of this need for integration and looking ahead, I mentioned a couple of times a critical technology that is getting more and more attention in the Congress, carbon dioxide removal from the atmosphere and the upper oceans. We did a portfolio analysis. DOE has a huge role. NSF has a huge role. Agriculture has a huge role. Interior has a huge role. NOAA (National Oceanic and Atmospheric Administration) has a huge role. I think that's the kind of perspective we need to bring to more of our critical challenges in terms of bringing it together, putting it before Congress, and going forward based upon sound analysis, and I think garnering, I would hope, strong bipartisan support.

Mr. LUCAS. My exact point.

Dr. Arnold, my time is expired, and I regret that.

Dr. ARNOLD. That's fine. I don't have anything to add here.

Mr. LUCAS. I yield back, Vice Chair.

Ms. STEVENS. Great, and thank you so much.

With that, our Madam Chairwoman Johnson has returned, and I will pass the running of the hearing back over to her.

Chairwoman JOHNSON. Thank you very much, Ms. Stevens, and thank you for filing in during my wi-fi failure. Let me thank all the witnesses as well.

Let me say that when I think about reimagining our innovation future, one of the things that's in my focus is how we need to be more inclusive in our approach to innovation. By inclusion, I mean

by gender, ethnicity, race, and disability, and institutional and regional diversity, diversity in expertise and in perspectives. I think about listening to those in our communities who might have something to say about the nature of our challenges and our research agenda, but who aren't traditionally connected to our local research institutions.

That's just not a moral perspective, but it's also an economic and national security imperative. And I just wanted [inaudible]——

Mr. BERA. Looks like we may have lost the Chairwoman.

Ms. STEVENS. I was going to say, I think her wi-fi went out again, and I know we've been having problems with that in various office spaces and whatnot. So, we need—what we'll do is we'll——

Mr. BERA. Do you want to recognize Ms. Bonamici, who's next?

Ms. STEVENS. Yeah, we'll just have to let Ms. Bonamici take it over.

Ms. BONAMICI. Thank you, Vice Chair Stevens, and thank you to Chairwoman Johnson and Ranking Member Lucas, and thank you especially to our witnesses for joining us today.

This hearing is about our innovation future, so as a Member of the Education Committee, I want to first note the importance of well-rounded education and educating students to be innovative, and to be able to, as Dr. Arnold noted, solve problems in new ways. A student may become interested in math by playing an instrument or learning chess strategy, by growing a garden or glazing and firing pottery can spark a child's interest in science. We need intellectually curious critical thinkers to solve the challenges we face and it is at our peril if we don't recognize that, which is why I'm leading a bipartisan call for robust funding to Title 4A grants under the *Every Student Succeeds Act* to support that well-rounded education that will educate students to be creative and innovative.

So, moving on, the United States has the ability and the obligation to lead the world's efforts to curb greenhouse gas emissions, and addressing the climate crisis is our next moonshot innovation challenge. Our Nation does have some of the world's best scientists, researchers, programmers, and engineers in the world. We can and should take bold action that is informed by their sound peer-reviewed science.

I have two questions for Secretary Moniz, so I'm going to state the two questions and then turn the time over to you to answer them.

Secretary Moniz, you in your testimony noted your work at the Department of Energy to develop mission innovation to accelerate clean energy research development and demonstration. We are anticipating that the Biden Administration will soon announce our next Nationally Determined Contribution (NDC) under the Paris Agreement, so how would you recommit or how would recommitting mission innovation contribute to a whole of government approach under an ambitious NDC accelerate our transition to 100 percent clean energy economy? So, that's my first question.

Then the second question, Secretary Moniz, following up on your comment about regional approaches. I appreciate that you highlighted that. In northwest Oregon, for example, we recognize the tremendous potential of marine energy, but the same researchers—resources are not accessible in landlocked States. So, regions differ

in energy resources, markets, and innovation ecosystems. So, as part of mission innovation, as you mentioned, you proposed funding during the Obama Administration to support those regional clean energy innovation partnerships. Last year, I introduced the *Regional Clean Energy Innovation Act*, which is modeled on this idea.

So, how can the Federal Government better harness and align local, State, tribal, regional, and national solutions to advance the deployment and commercialization of clean energy technologies and help innovative concepts avoid that commercialization valley of death? And I'll turn it over to you, Secretary Moniz, for your response.

Mr. MONIZ. Well, thank you, Congresswoman. Very good questions.

Let me say on the first question on mission innovation, I do expect, as you implied, that the administration will put forward a very ambitious NDC probably next week, and it will have an extraordinary challenge for the electricity sector by 2030, and then, of course, economy-wide reductions. If I had to guess, it would be north of 50 percent reductions economy-wide in line with the EU, for example.

Now, as I said, to reach that, we need what I called supercharged innovation for this next decade that will include international collaboration, and I think now that we have rejoined the Paris Agreement—and I will give a shoutout to the Deputy Secretary, Dave Turk, who when I was Secretary already was playing a role in stewarding mission innovation, and he continued to do that at the IEA (International Energy Agency). So, I think Dave could play an important role in our getting back into mission innovation. But importantly, expanding its scope.

I mentioned two areas. Carbon dioxide removal is absolutely essential if we are going to meet net zero, and almost by definition, if we're going to get eventually to a negative economy, we need negative carbon technologies. That's a perfect area for international cooperation.

Another more challenging organizationally, but I believe the advanced nuclear technologies—and by the way, that includes one from Oregon——

Ms. BONAMICI. Right.

Mr. MONIZ. Yeah. Seriously need a public/private partnership because enormous amounts of private capital have gone in, but they have to get over the hump in terms of demonstration.

On the second issue I'll be very brief, but you said it. The low carbon solutions will look entirely different in different parts of the country, No. 1, and therefore, we should have some regionally driven innovation that will look at the solutions most appropriate to that part of the country, engaging their own innovation institutions to advance that.

Secondly, I believe the regional innovation centers, as I said, will be very important for the inclusive nature that we need of our system, and although it's the opposite end in a certain sense of the commercialization, I would say that starting in the 1970's—while I have to say it wasn't very popular at some of our leading research institutions, I was and I remain a major fan of F-score as a way of reaching areas and young students' talent that we need to bring

into the system. I believe that can be a very effective mechanism as well.

Ms. BONAMICI. Thank you, Mr. Secretary, and as I yield back, I want to say if I had more time, I would ask Dr. Arnold about the importance of childcare, which I know you mentioned in your testimony.

But I will yield back and submit a question for the record. Thank you.

Ms. STEVENS. That's a great one, Rep Bonamici, and thank you for that.

I see we've got Chairwoman Johnson in the Committee Room. All right. Chair Johnson? I know we had Mr. Posey next in line here, which we can pass it over to Mr. Posey and then jump back to Chair Johnson so she can finish her questions. But however you'd like to proceed, Madam Chair.

Chairwoman JOHNSON. Thank you very much. Who is the next witness? I have changed locations.

Ms. STEVENS. We had Mr. Posey up next for questions.

Chairwoman JOHNSON. Mr. Posey is recognized.

Mr. POSEY. Thank you very much, Madam Chair, and I must say, I appreciate your passion toward the subject of innovation.

And I hope we all recognize that China's economic and military goals are one and the same. Through economic dominance, they hope to achieve military superiority. So, this has been mentioned by two of the speakers already, intertwines with our national security.

Mr. Augustine, in your testimony you state that America is on a path to lose its lead in science and technology to China. What are your recommendations as to make America competitive well into the future, and to fix our Nation's Pre-K through 12 public school system, particularly in STEM? Would you be willing to give us more specific recommendations?

Mr. AUGUSTINE. Thank you, Congressman. I'd be happy to do that. Perhaps the—there are two missing links—I know there are many, but two major ones that are science and technology competitiveness. One is a lack of investment and the second is—seems—the ability to produce scientists and technologists from domestically born children at scale. And certainly, there are some outstanding young people with some outstanding schools, but on average, by international standards we're failing.

Part of the issue is having teachers who aren't qualified in science and technology. Too often middle school children have teachers who are the football coach and they've been given a book on algebra and said go teach algebra. We have too many teachers not qualified to teach the subject they're teaching in the STEM area. And that certainly has to be fixed.

The problem, for once, is not money. We spend more money per student in pre-K through 12 than any other Nation but one, Switzerland. And our problem, I think, is to bring the free enterprise system, parts of it, to our public education system, which means that one has rewards for outstanding performance and accountability for poor performance. Somehow, that has been very hard to do because we have—I think it is 14,000 public—I should say independent public school districts.

I'm optimistic that we can solve the financial part of this issue. The K through 12, and you said pre-K through 12, which is really important because too many of our young children start first grade 2 or 3 years behind, and pre-K is just essential if we're to solve this problem.

So, thank you for that question, Congressman.

Mr. POSEY. Thank you for your answer.

You also mentioned in your testimony and you mentioned it orally, a balance between technological breakthroughs of warfare history, they're the stirrup, the longbow, gunpowder, the cannon, machine guns, tanks, battleships, aircraft, nuclear weapons, rockets, and night vision, stealth, space, robotics, autonomy, and cyber. And I'm just wondering what you see as the next technological breakthrough, and do you see the United States taking the lead with it?

Mr. AUGUSTINE. One of the wonderful things about technological breakthrough is that most of us can't foresee them, and I'm afraid I'm in that category. But to try to answer your question, there are some areas that certainly stand out as being at the leading edge of science today, and I defer to some of my colleagues on the panel. But artificial intelligence stands near to the top—as does quantum science with its several applications. We often talk about quantum computing, but there are many more applications. Robotics, autonomy, autonomous vehicles are being seen already, and certainly biomedical sciences—that's where I think the really big breakthroughs are going to come in the decades ahead.

One of the great things about some of the proposals that have been made for legislation would be to have the NSF put together a group of people who are really qualified to answer that very tough question, and see if they can come to a consensus, and then readdress it periodically.

One of the important things in my last 19 seconds of your time, I would just point out is that, as my colleagues have said, being first in research is of the utmost importance. That's where the ideas come from. My background is mostly in business, but research is where the foundation is. But ideas left in the research lab are of little value in terms of winning wars or succeeding in the market.

I see my timer is at zero, so thank you, Congressman, for your question.

Mr. POSEY. Thank you, Mr. Augustine. I yield back, Madam Chair.

Chairwoman JOHNSON. Thank you very much.

Our next witness—Mr. Bera.

Mr. BERA. Great. Thank you, Madam Chairwoman.

Look, this is a great conversation. One thing that I'd add to Mr. Augustine, when I think about my public school education, I also had wood shop, metal shop, auto shop, which I do think we've really disadvantaged a generation of kids by not having that exposure to the arts and—you know, where you have to use your imagination.

Now, I went on to medical school, and when I was training at UC (University of California) Irvine, most of the Ph.D.'s that we were training with were going on an academic track. They'd go into academia, and then join faculty and go on a tenure track. Fast for-

ward to my professional life prior to coming to Congress as an associate dean and faculty member at the University of California, Davis Medical School, most of the Ph.D.'s that we were training there were now actually getting their training and they were going to go into the private sector or startups—not all of them, but many of them, you know, were going in that space.

And you know, I think the right mix—and again, Mr. Augustine, you touched on this a little bit—is how do we get that blend of academia, and you know, private sector innovation? When I think about academics, we are doing research and discovery just for the joy of solving these problems, not necessarily thinking about how we are going to commoditize it and bring it to the masses. Private sector is thinking about how you commoditize it and get it to folks.

So, maybe I'll start with Dr. Arnold and then to the rest of the panel. You know, one of the areas that I have thought a lot about is this area of technology transfer, and private institutions can do technology transfer a little bit easier than public taxpayer-funded institutions. Yet, I'd be curious—and again, maybe starting with Dr. Arnold, what things should we be thinking about doing to make that tech transfer, you know, a little bit tighter and easier?

Dr. ARNOLD. Right. Well, first of all, let me just say I'm the mother of a young man who got his education and tech through the U.S. Army, so that's a wonderful training place for hands-on technology, and he built the Mars rover at JPL (Jet Propulsion Laboratory) after leaving the Army. So, there are wonderful careers in hands-on technology that young people should know about and should be ready for, and we shouldn't have to rely just on the military to train these people.

Now, to answer your question, I am—what should we do to promote tech transfer in places is make it easier. Technology is not useful until someone uses it. Academics are very fond of saying this is useful for something, but they have no clue what it takes to get it into the hands of real users.

On the other hand, the young people who actually do the development of the technology, who invent it, want to do that, and so, to the extent that we can support the transition of some of these young graduate students into the entrepreneurial space, we should do that, as often happens in California. California has a thriving ecosystem for that. To the extent that we can do that in other parts of the country, all the better. I think you'll see that the students have the passion and work ethic needed to make that happen in the right environment.

Mr. BERA. Dr. Jahanian?

Dr. JAHANIAN. Yes.

With respect to your comment about education, I just want to add one point and then I'll talk about technology transfer.

I think we're at a point in this country that we need to be reimagining not only K through 12, but also higher education, because we're going to have to break down disciplinary siloes. I think some of the most important advances that we're making, both on the discovery side as well as on innovation and its impact on society, are inherently becoming interdisciplinary, bringing people from different perspectives. So, one of the important things to recognize

is that it is the convergence of disciplines that's really catalyzing now some of the innovation that we're seeing.

Very briefly with respect to your very profound question in regard to technology transfer, what I can tell you in my experience over the past 25 years in academia is that U.S. academic institutions have come a long way. We do have one challenge, which is something that I mentioned, and also Secretary Moniz mentioned, which is that we need to expand the geography of innovation in the U.S., and the best place to do it is to look at where the concentration of research is happening. In fact, in the U.S. today, we have about 200 institutions that are receiving more than $50-plus million in R&D, and that could be an innovation center that could catalyze innovation, working with the private sector, working with the economic development in the regions, and so on.

So, one really important concept to recognize is that going from lab to market doesn't happen on its own. We need to create the conditions. We need to create the environments to facilitate transfer of knowledge from lab to practice, from lab to market, creating new industries and products.

With respect to the universities, at Carnegie Mellon, for example, we have created a culture of innovation such that our faculty, students, and researchers don't just think about foundational versus use-inspired research. They think about the entire continuum. But most importantly, we have direct engagement with the private sector, and the private sector is often involved in research with us, especially in the area of use-inspired research, creating much more flexible policies for faculty members to be able to transfer their knowledge to practice, to be able to leave the university and come back. Again, at our institution and I know many other institutions in the country, we've made that possible.

The final point related to the students is that our students in this next generation are hungry for the kind of use-inspired work that you described.

So, I think our challenge at universities has been—and I think we've come a long way, is to create an entrepreneurial culture in the university, such that those who want to engage in it, whether they're undergraduates, masters, or Ph.D.'s, can do so. I am very optimistic about how far this country has come in terms of being able to facilitate this. We have some work to do, but there are some terrific examples of successes in this country in terms of the innovation ecosystems that we've created at universities that involve the community, leading to economic development and job creation that could be replicated across the country, hence expanding the map of innovation.

Thank you for that question.

Mr. MONIZ. Madam Chair, may I add a brief comment?

Chairwoman JOHNSON. Yes.

Mr. MONIZ. Just to say that I agree with all of that, but I don't want to lose sight of the fact that as has been said, the most important vehicle for tech transfer from the university is the moving van which takes our graduates to their next job.

Chairwoman JOHNSON. OK. Mr. Clerk?

The CLERK. Mr. Babin is next.

Mr. BABIN. Yes, thank you so very much, Madam Chair, and Ranking Member Lucas. What fascinating testimony here. I want to thank our witnesses for being here today. One of the greatest assets we have here in this country, as we've just heard so eloquently, is our vibrant venture capital market, the private sector. When we fully utilize the R&D capabilities of industry, we have the ability to dominate global innovation in science and technology. The partnership we have with the private sector is a unique advantage that we have, and one that sets us apart from other countries, who heavily subsidize R&D investment that is almost solely reliant on government funding.

And now, thank you, Dr. Jahanian, for what you said, but I would like to ask the same—this question here of Dr. Arnold and Mr. Augustine. How do we make certain that we fully utilize this unique edge and partnership that we have with industry, and how can the government improve collaborative efforts with the private sector? I heard Dr. Jahanian, and I'd like to hear both of your opinions. Thank you.

Dr. ARNOLD. Thank you for the question, Representative Babin. I've worked extensively with industry over the years. The problem, of course, is that industry has outsourced much of their fundamental research, and they have very short timelines for solving problem, and I'm talking about the big companies. And that's usually not the best partnership with, let's say, you know, elite laboratories that are trying to do the cutting edge research that will change the world in 10 years, or 20 years. So there's a mismatch of time scales for industrially sponsored research. However, to the extent that companies are investing in the next generation of technology in their spaces, that seems to work very well, when the timelines are loosened a bit.

Mr. BABIN. OK, thank you. And Mr. Augustine? I think you're unmuted, Mr. Augustine. Go ahead.

Mr. AUGUSTINE. Can you hear me now?

Mr. BABIN. Yes.

Mr. AUGUSTINE. OK, good. Such an important question. My background is in industry, government, and academia. I've had three careers, and our system of producing new ideas and putting them in the market is really a three-legged stool. It depends upon these three elements. It—the government is going to have to be the funder of default of basic research. Industry just isn't going to do that under today's rules, with today's taxes and so on. So the government is going to have to fund basic research. That research will best be performed at our universities and National Labs. It used to be performed in industry, but industry can no longer afford long term investments of that type, high risk.

When I first entered industry, the average shareholder held their stock for 8 years. Today they hold it 4 months, and they don't care what happens to the company 8 years from now. So industry will invest heavily in development, but not in R. So that's so important that the government fund R. Academia and the National Labs perform R, and then transition it to industry. And to pick up on Ernie's point, I've always felt the best way to transfer ideas between those three elements is to transfer people, and so the more easily that we could make it for people to move among those three

elements, one to the other, I think we'll find transitioning much easier. Thank you for a great question.

Mr. BABIN. Yes, sir, and I think I've got time for one more. The FBI (Federal Bureau of Investigation) and intelligence agencies have warned Congress about the threat of foreign espionage of U.S. science and technology, particularly on university campuses. So China's investment in development, and not on basic research, implies that they are building their technological success on the basic research developed in the United States, and around the world. We've seen infiltration of Chinese influence in our university systems in several different occasions at our top institutions. So how do we ensure that foreign nationals from China coming to study at our universities do not undermine our open system of research? And what is the right balance for protecting U.S. basic research while continuing to promote an open science system that has made our scientific enterprise the best in the world? Dr. Arnold, I'd like to have you start with that.

Dr. ARNOLD. Well, Representative, I work in a field where the openness is a great benefit. It causes all boats to rise. And it's not related to national security. So I see the huge benefits of having fully open science, and I don't worry about infiltration from China because, frankly, the talent of the students who come make that research go forward. On the other hand, I recognize that there are areas of research where perhaps the openness should not be as open, and I'll leave the answer to those who know that better.

Mr. BABIN. OK. Anybody else like to take a stab at it?

Mr. MONIZ. Go ahead, Farnam.

Dr. JAHANIAN. I was just going to say that, as you said, that we need to preserve and enhance the research, education, and innovation ecosystem that has fueled our Nation's prosperity since World War II. This is a model that we know has worked, and it is not a surprise that others are trying to copy it. Having said that, your question is very profound, and it's really important. There are areas of research in which openness is so important to the long term success of our own science and discovery enterprise, but we also recognize that foreign influence in the form of intellectual property theft, cyber attack espionage, other broad-scale state-sponsored efforts are a direct threat to our Nation's security and economic prosperity. And it would be a mistake to think that this is only happening at universities. This is happening across the board, and we have to be ready for it.

I can give you my assurance that academic institutions in this country, including Carnegie Mellon, my home institution, are taking significant steps to protect against these challenges when it's appropriate. Again, openness, as Professor Arnold mentioned, is so important to the research enterprise of this country that has served our national security and economic prosperity so well. As examples of things that we're doing, we're being very diligent in protecting against some of these challenges, in working with other institutions; working with, obviously, policymakers; building awareness; increasing coordination; training faculty and staff; reviewing collaborations, contracts, and foreign gifts; reviewing, updating, and enforcing conflict of interest policies; implementing foreign travel

safeguards and protections; developing requirements and vetting them; and so on.

We need to double down on what we do best: leading the world in innovation, creativity, and finding solutions to society's most pressing challenges. In fact, many international students that come here want to stay, and they contribute so significantly to the culture of our academic institutions and our entire Nation. Our research enterprise has been so successful because we are solving some of the most pressing challenges for society.

So instead of hoping that others will lose, I think we need to double down in the belief that when we win, when America wins, the world wins. We need to continue to ensure that our Nation remains a welcoming place for those who want to maintain our competitiveness, be part of our society, and contribute to it. And also, that's part of the reason that I believe we should not retreat from global engagement. We shouldn't change how we do research. We must not cripple the engine that has delivered amazing benefits to the country, while recognizing that we do have challenges—in the private sector, and academic institutions, and the government.

And the very final point I want to make is that the biggest threat to our economic prosperity and national security at this point in time is cybersecurity, without any doubt, the cyber threat to this country. We need to absolutely double down to deal with cyber issues. Thank you.

Mr. MONIZ. My——

Mr. BABIN [continuing]. Time.

Mr. MONIZ. My simple point was that we can't kill the golden goose, so we need to support the open system, but what we also need to do is to get the clock speed up from that basic research to the ultimate products so that it is, in fact, a material advantage to us to have that open fundamental research system.

Mr. BABIN. Thank you very much, and I'll yield back, Madam Chair.

The CLERK. Mr. Bowman is next.

Mr. BOWMAN. Thank you so much, Madam Chair, and thank you to all of our witnesses providing testimony today. I would want us to maybe shift our paradigm a bit. It's good to think globally, but I also want us to think about the untapped and unlimited potential we have here in our country. I would propose that our golden goose is in our historically marginalized communities, our red lined communities, where we have historically underinvested in our schools and in our neighborhoods, particularly in our pre-K to 12 school system.

And I'm so happy that so much of this conversation has focused on our pre-K to 12 school system because, you know, I've had the privilege of working in pre-K to 12 schools for 20 years, in all Title I school districts, and I've worked in elementary, high school, and middle schools. I've been a middle school principal for over 10 years, and I could tell you that our kids are ready, willing, and able for more science and technology in the classroom, they're ready, willing, and able for more innovation. They are curious, they are collaborative, they are creative problem-solvers, and they are waiting for us, as the adults, to get our act together and bring them more curricula and instructional opportunities. So I think a focus

on K to 12 with regard to science, with regard to arts—we spoke earlier about hands-on learning. Our kids are ready for all of this, and they're tired of the mundane, rudimentary education that we've been giving them for the last 20 years, so it's great to hear you all speak about the importance of K to 12 education.

Dr. Arnold, thank you so much for your testimony, and thank you for highlighting the difficulties that marginalized children face in pursuing STEM careers. For example, if they fall behind in math and science in middle school, as you mentioned. I recently proposed a green stimulus investment of $1.16 trillion over 10 years to make each of our public schools a healthy, zero carbon center of the community, and a big part of that vision is seeing our schools as living labs and putting our young people at the forefront of the sustainable energy transition. Given your work in biology, engineering, and green energy, I'm wondering if you could talk more about how solving the climate crisis is an opportunity to engage children on a deeper level here, to ignite their passion for learning across a variety of STEM fields, and to set them up for a variety of careers?

Dr. ARNOLD. Representative Bowman, you've seen it with your own eyes, the children are passionate about making the world a better place, and they've always been, right? Remember how we were. Unfortunately, my generation is leaving them a world that doesn't look like a better place. We may be leaving behind a world that is worse in some ways than the one I entered, and I feel ashamed about that. I would like to see those children empowered—again, the word is empowerment—empowered to make decisions about the future, about their education, about their careers that will enable them to make a difference.

Science and technology is an incredibly powerful way to do that, and that's what I tell the young people. They need to know that, through science and technology, they can make an impact on these major problems, and what better challenge than climate change? Because that touches everything.

Mr. BOWMAN. So just a follow-up question, if I'm a teacher in a second grade classroom, and I want to introduce my students to the world of science to put them on a pathway toward solving the problems that we all know are pressing, not just climate change, but other problems as well, what is the best way I might do that, Dr. Arnold? And then others can chime in.

Dr. ARNOLD. Well, I'm not sure I'm the best second grade teacher, but I have raised three sons who are all curious. I found that just taking them out and showing them the world. and not being afraid of it, teaches resilience, curiosity and willingness to test the unknown. We've—we tend to often imbue our children with fear rather than confidence, and fear of the future is not an effective way to instill creativity. So confidence, getting out into the world, making things happen, seeing things happen, getting out into nature, observing. Observing with your own eyes, building with your own hands, it's a very hands on thing, science is, so anything that can do that, get them out of the Zoom room, and out of the classroom, and into the real world helps.

Mr. BOWMAN. Thank you so much. Secretary Moniz, did you want to jump in with a quick response?

Mr. MONIZ. Well, I would just add that, again, I was not a second grade teacher, but my grandchildren are—have just gone through that phase, and I think the big thing is science is fun. Science is remarkable, and I think it goes back to what Norm said earlier, that's the teacher cadre that we need, that has the confidence, the interest, the excitement, to say, wow, you know, if we get these kids to see what science is about, remarkable stories, I think we'll get a new generation.

Could I also add that I think it's very important, of course, the role of parents and mentors, et cetera, and on the climate side we are going through a big change in which people of our generation see with their own eyes that climate change is not only an issue for their children and grandchildren, it's for them too, because we are paying a lot. I mean, look, the recent Texas stuff would be an example of terrible results. And so maybe that will help the mentors also understand that this is important for the kids, to have that STEM education.

Mr. BOWMAN. Awesome. Thank you so much. I yield back.

The CLERK. Mr. Baird is next.

Mr. BAIRD. Thank you, Madam Chair, and Ranking Member Lucas, for having this important kind of a session. I've really enjoyed hearing from Mr. Augustine in the past, and again today, and I really appreciate all of the witnesses and their testimony. I think we've touched upon some very important things to help keep our country in a leadership role, particularly in STEM education, because it's so important to our future. It's becoming increasingly important, and a matter of national security. So with an institution like Purdue University in my district, and I might mention that they just recently was ranked fifth as the most innovative university in America by *U.S. News and World Report*, but I only mention that because they have the research part that's adjacent to the University. It really provides innovators the opportunity to take the information they get out of the lab and have a space to work, and be innovative, and develop their own company. So it really takes the lab research, and the results there, and puts it into practical application. And so I think that's really important to our growth and development in this country.

I also really appreciate what Dr. Bera had to say, and also Representative Bowman had to say, regarding stimulating young kids, and utilizing their curiosity that was mentioned in order to do the pipeline and build a pipeline with young people that want to be in the STEM education. If you tell them that you want to make them STEM researchers and so on at a very young age, I'm not sure how excited they'd get about that. But what I have experienced in some of these facilities that I've seen, getting the hands-on, the opportunity to challenge themselves, and something exciting really does stimulate them, so I guess, Mr. Augustine, I'm going to start with you. By the way, I really appreciated having access to the "Perils of Complacency," but would you care to elaborate on—are there other ways that we could stimulate these young kids? I'm thinking about Boy Scouts, the FFA, 4H, where they get that hands-on experience, that's already in place. What's your observations or experiences there, Mr. Augustine?

Mr. AUGUSTINE. Well, thank you for that question. As a former President of the Boy Scouts, I appreciate the comment. They had merit badges in science, and aviation, and space, and you name it. There are many organizations outside of schools as you suggest that are doing wonderful work, and if it could be made available on a broader scale—I think of such things as the Challenger Center, I think of such things as FIRST Robotics, started by Dean Kaman. FIRST Robotics has a program that goes all the way from preschool through high school, and it starts out with a LEGO competition, building robots. And when you see these kids working on these things, they're so excited. It's unbelievable how they get into it. I think emphasis on these out of school things could be very, very important.

I think there's another factor that gets into the preschool part of it. We're operating our science and technology enterprise with one hand tied behind our backs. And I say that because 58 percent of our college graduates are women, but only 19 percent of our Ph.D.'s in S&T are women. 40 percent of the students in our pre-K through 12 public school system come from under-represented minorities. They produce 7 percent of the Ph.D.'s in science and technology. If we could just get more of these young kids interested, keep them interested and excited, we could solve much of the problem we have with China. I think back to my own career. Who would have ever thought that a kid from Colorado would help put people on the Moon? This is exciting stuff. Thank you for your question.

Mr. BAIRD. Absolutely, and you know, you talk about women in the STEM programs, Representative Stevens, and I see she's on here, we sponsored a bill way back in the last Congress that encouraged young women to get involved in the STEM program. I am sorry that I don't—I've got several other questions, but I'm out of time, and so I really appreciate the other witnesses and their testimony. I found a lot of interesting comments that you made, and I appreciate it. I yield back.

The CLERK. Mr. McNerney is next.

Mr. MCNERNEY. Well, first of all, I want to think the witnesses. Great testimony, and it's great to see you all in front of us today.

Dr. Moniz, we have to focus on mitigation and adaptation for climate change, but is it now the time for serious investments in climate intervention, i.e. geoengineering research, so that we have that as an option in the future? You will need to——

Mr. MONIZ. Sorry, I was muted, I was muted. Yes, a very important question. First of all, let me make the—first of all a distinction. There's sometimes confusion, I don't mean in this Committee, but—between carbon dioxide removal and geoengineering. I think on the carbon dioxide removal we need a big push in this decade toward demonstration and deployment so that we can address legacy CO_2 in the atmosphere and the oceans. Geoengineering gets into much more difficult issues. I personally support highly regulated R&D getting into perhaps localized demonstrations, but maybe we need a structure like NIH review boards, for example, to do that. I—to be perfectly blunt, I sure as hell hope we don't need it, but I think we have to do cautious and prudent investigations in case we need band-aids for a while as we address the core issues of mitigation.

Mr. McNERNEY. Well, moving on to fusion, what do you think the state of affairs is with regard to fusion as a potential energy source, including low energy nuclear reactions?

Mr. MONIZ. OK, well, let me first declare that I'm on the board of one of the privately funded fusion companies in Southern California, in fact. The fusion—first of all, a lot of people are surprised that fusion has probably attracted—alternative fusion concepts has probably attracted $1–1/2 billion of private capital. It's an unknown story, and that's happened because the progress is quite stunning. The company that I'm associated with, TAE, for example, put out a press release last week kind of admitting that we have reached stable temperatures approaching the 100 million degrees needed for DT fusion. At MIT there's a spinout that within months will be testing novel high temperature superconducting magnets that can make a compact tokamak design feasible.

So we are—what I would say is in this decade we'll know if this dog hunts. And if it does, it is a big, big deal, because, of course, it doesn't have the challenges of fission, which is also doing remarkable things, remarkable innovation in advanced small fission reactors. But fusion would be an even greater breakthrough, and just change the—it would literally change the world.

Mr. McNERNEY. Thanks. Yeah, I'm pretty excited about fusion too.

Mr. MONIZ. Yeah.

Mr. McNERNEY. Dr. Jahanian, as co-Chair of the Artificial Intelligence Caucus, I want to make sure that we in Congress are taking the necessary steps to make sure our Nation stays competitive in AI. What metrics should we be examining in order to evaluate U.S. competitiveness in AI against significant players like China?

Dr. JAHANIAN. Thank you very much for that question. As you know, advances in AI are probably among the most important developments in scientific discovery and innovation over the past probably quarter century, among a handful of others. Before I get to your question, I do want to highlight an important thing about AI, which is connected to basic research and importance of investing in foundational research.

You know, we all look at AI and think that it just came to fruition overnight over the past few years. The truth is our Nation is leading it because for the past 40 to 50 years we have invested in foundational research that has led to artificial intelligence. And, in fact, some of the advances in machine learning, deep learning, and so on, have happened as a result of these major investments that the National Science Foundation, and then other mission-oriented agencies, including DARPA (Defense Advanced Research Projects Agency), DOE, and NIH have made in advancing AI. The importance of that is really something that I want to get across, because that 30 or 40 years plus investment in research is now bearing fruit, and it's having impacts in various areas, as you know, from healthcare to manufacturing, in national intelligence, national defense, and so on.

With respect to metrics, I think there are a number of them. One is we really do need to make sure that our production of talent in this country matches the pace and scale and scope of innovation that's needed. The second thing that's important is to look at the

application of AI in various areas, as I mentioned, whether it's in healthcare, whether it's in manufacturing, whether it's in smart transportation, whether it's in energy and climate, and so on, and develop metrics around that to see the progress that we're making.

The last point that I want to make is that we need to be very cognizant of what's happening in the rest of the world, and continue to out-innovate and outpace our competitors. Because of the importance of AI, we see massive investments, as others have alluded to, by our partners and competitors across the world, including China, so we can't take our eyes off the ball.

Mr. MCNERNEY. Thank you. Well, my time has expired. I'm embarrassed that I didn't get to ask a Nobel Prize winner a question in the Science Committee, but I'll submit something for the record. Thank you. I yield back.

The CLERK. Mr. Sessions is next.

Mr. SESSIONS. Chairwoman Johnson, thank you very much, and our Ranking Member Lucas, thank you for doing this. To each of our three important people who are providing testimony today, I want to focus, if I can, on two issues. No. 1, I would like it to be said that if it's just a snapshot today, one would assume that we've been laggards and not paying attention to this issue for the past 15 years, when in fact we have, and we've done a number of things, including, as an example, the NIH, taking them on a 5-year model where we did not make them come up and beg under discretionary spending. We put them on mandatory. We gave them the money and said, "Please come to us to keep us updated. Don't come to us to beg to get money", and we did that. Second, we did right to try. We've done a number of things that have been very influential. We funded genome project years ago that would lead us to where Francis Collins is not today, but where he has been, that helped us at the time of the pandemic.

So I would like for it to be noted in the record that for quite some period of time, between the Energy and Commerce, the Science Committee, and the Rules Committee that we pushed an aggressive agenda, including the Budget Committee, where we doubled—this is not a new term—doubled back in 1997 the NIH and other funding. Now, that said, thank you very much, we appreciate you being here.

Dr. Moniz, this may be directed directly at you and Professor Augustine—Mr. Chairman Augustine. Please know that I've heard the discussion now about TAE, the company which Mr. Moniz, that you are affiliated with, and thank you very much, that is directly related to fusion. But another example I'd like to bring up is a company called Urenco, and Urenco is the world's leader from back in World War II of uranium enriched services. Urenco is, by and large, until they get pushed out of European countries that don't like atomic energy or fusion—they exist in New Mexico, and they are the world's leader, by far, in these uranium enriched services. Close to fusion, not the same thing, but they have to begin with the same product.

My point to you, and question now, with 2 minutes left, and I apologize, although we just went through, with Mr. McNerney, a little bit extra time, I'd like for you to discuss why in the world would we pay our labs or people here to compete against someone

like TAE and Urenco when they've already solved the problem, and they, because they're in a free enterprise system, are driven to making things better every day, why would we pay $50 million to Oak Ridge Labs to try and learn how to do what we already know? Mr. Moniz?

Mr. MONIZ. Thank you, Mr. Sessions. First of all, on the fusion side, I should say that if I just use the company that I'm affiliated with as an example, it's a partnership with the labs, actually, has also been very important because the Department of Energy has provided large-scale computational services. And that, together with a partnership with Google on machine learning, all these things come together for the progress, so it's really an ecosystem there.

On the enrichment side, Urenco, as you said, is certainly the leader in the West for sure. If I may note, however, we have a, in my view, pressing need in the United States to deploy an American enrichment technology because that's the only way we can serve our national security needs, and those national security needs range from making tritium for the nuclear weapons stockpile, eventually to making fuel for nuclear propulsion, and, in the near term, producing what's called high assay LEU (low-enriched uranium), 20 percent, roughly speaking, enrichment in order to satisfy some non-proliferation objectives, and to support the innovation going on in fission because most of the new designs that are being—and many are supported by the Department of Energy—almost all of them require this so-called high assay LEU. So we need to focus on getting an American technology out there to meet our national security needs quite separate from competing in the commercial market.

Mr. SESSIONS. Well, OK, so—but we go to SpaceX to get the commercial market for what we need for NASA and other things.

Mr. MONIZ. Yeah, well, the—I mean, the—this national security service could be provided by a commercial entity, as long as they are using American technology, and American equipment, and American uranium because all of that is required by our non-proliferation agreements.

Mr. SESSIONS. Well, they're in New Mexico, and doing quite well. They're a——

Mr. MONIZ. Yeah.

Mr. SESSIONS [continuing]. Big power organization. Look, I'm just trying to get the concept, not the specifics, but sometimes in the concept you have to use an example, and that's why I tried using an example, TAE. You gave a great answer. I will just go to the premise, Mr. Augustine, and Ms. Arnold. I'm not trying to ignore you at all, because I think you bring a lot of common sense as much as anything. Norm, you bring a lot of realistic ideas about specifics. Should we be funding, through the Federal Government, things where there already is a world leader in trying to understand it, as opposed to spinning off our limited—or lots of resources, but the limited resources of trying to compete, as opposed to go build something. I'm worried about the competitive model, about government against something that's already been solved. Norm?

Mr. AUGUSTINE. Well, thank you for the questions. If I could go back to the first part of your comments, they were so important, your Committee has played a key role in trying to keep America ahead in science and technology, and I think what's happened over the years, the past dozen years or so you mentioned, is in one word China. China has come along so fast that that it has become a concern. Secondly, I think that regarding your second part of your comments, fusion is the ultimate answer to the energy problem for the world. And it's come very slowly, tough technical issues, but there are projects in being—progress being made.

Turning to the issue of fission, which we tend to neglect, small modular reactors offer a great deal of promise, another new development. We have to pick and choose—there's no such thing as second place, if it's an area that's of critical importance to us. I would say microelectronics. Microelectronics are the heart of all modern technology, if you really get down to the fundamentals. But we build now only 14 percent of the microelectronics in the world. Now, that might be an area where we would want to build up our own capability even though others have ample capacity. But there's no sense reproducing things that our allies, reliable allies, are producing. Thank you.

Mr. SESSIONS. Ms. Arnold?

Dr. ARNOLD. Thank you. I think that the general idea that you're putting forward is that we shouldn't reproduce what already is happening in private industry as long as it's happening well, and there are many examples where private industry is fully capable of developing the technology, and, in fact, better capable than a research laboratory would be doing, so I'm all in favor of that. But you also have to supply people to support those industries, so the education of those people is critical. No technology exists as a silo.

Mr. SESSIONS. Well, and that's the last point—Chairwoman Johnson, I just would request 15 more seconds. And this is why we made permanent R&D tax credit, so that companies could go and plan it in their long term strategy, as opposed to "worrying every year", so I think we're going to get there. Chairwoman Johnson, thank you. Our three witnesses I find leading edge in the world, and I appreciate all three of them. Norm, thank you for your service to the Boy Scouts of America.

Chairwoman JOHNSON. Thank you very much.

The CLERK. Mr. Foster is next.

Mr. FOSTER. Well, thank you, especially to all our witnesses, for your great written testimony. I stayed up far too late last night getting through it all. There appears to be a real appetite right now on both sides of the aisle to increase Federal funding for scientific research. You know, this obviously could result in a fantastic opportunity to propel forward enormous advances in science and research nationally as a sort of second Sputnik-like moment.

Now, some of those proposals involve significant—renaming and mission change in our scientific enterprises, while others see the existing structure as primarily sound, but historically under-resourced, and basically just want to increase the amount of money there. And I guess Secretary Moniz has mentioned this, and I just was wondering if we could go through the witnesses and ask what your thoughts are on this general area, whether the first priority

is just ramping up the budgets for the existing program versus structural change in this. And I guess I—we'll start with Mr. Augustine, who was a practicing engineer during the first Sputnik moment.

Mr. AUGUSTINE. Well, I was, and thank you. I think that both are important. Certainly if we don't increase the financial support for research from the Federal Government, we're going to be in trouble, and I say that because industry simply—the old Bell Labs, or the great places like that—Bell Labs a canonical place, the home of the laser, the transistor, nine Nobel Laureates, is now owned by a company in Finland. So the government is really going to be the funder of only source.

You also point to another problem, and that is these three entities that are involved here, the Federal Government, academia, and industry, don't work together as well as they could. The reasons go all the way from excessive regulation to, frankly, some distrust of one another. And, having been at all three of those entities, I've found wonderful people, dedicated people, competent people, but there is a bit of distrust, and somehow we have to tie those organizations together so that one plus one plus one is seven, or something like that. I think we could do it. Thank you.

Mr. FOSTER. Yeah. Yeah, Frances?

Dr. ARNOLD. Thank you. I—so structure is important, right? Money is important, structure is important. Structure can also be destructive, so it has to be very carefully thought out how to put together a structure that fosters the creativity. I personally am a bottoms-up person. I believe that the creativity lies in individual PIs, individual entrepreneurs, and individual research scientists in companies, however, without the structure, much of that goes to waste. So I'm very interested in seeing how a structure will develop to make this seamless transition from discovery to getting it into the hands of people can best be formed.

Mr. FOSTER. Yeah. Farnam? Whoops, you're not muted—you're still muted.

Dr. JAHANIAN. Thank you for that question. There is no question that we need to increase investment in research in this country. It's indisputable, as I mentioned earlier. We see that our adversaries and our partners across the world are taking a page out of the recipe for success of our country. For the past 75 years these investments have made us enormously successful as a nation, and benefited the country in immeasurable ways, so we need to match the scale and the pace of the discovery with the investment that goes into it. The structure, as the other witnesses mention, is extremely important, and, again, it's because of the pace, scale, and scope of the discoveries and innovation that we need to be creative about new structures. However, forcing down certain structures on agencies has a significant risk associated with it. We have to be very deliberate about it, and in particular in the context of the National Science Foundation, since I understand NSF well, I think providing flexibility to NSF is going to be, in the long run, extremely important in ensuring that we cover the entire continuum.

My final point is the reason we need the structure and the investment is the urgency of the moment, but we can't forget that the

investment has to happen along this entire continuum. Thank you again for that question.

Mr. FOSTER. Thank you. And I guess I'm out of time, but Ernie's already made his feelings known on this in his opening remarks, I guess, and my time is up, and——

Mr. MONIZ. I'm happy to add, but that's up to the Chair.

Mr. FOSTER. OK. Well, if there are a few seconds left here, I'd just like to point out the merit in the sort of non-standard way that the Federal Government can invest in businesses to help them support research. An example of this was something NSF used to do called Moses, where they provided access to foundries, to universities, at a heavily subsidized rate, and I was sort of heartbroken to see that that seems to have stopped. But that's an example of Federal investment that would support something that's not profitable to the company, but very profitable to the long term health of our country, simply because businesses have advanced technology and capabilities that universities can't realistically have. And——

Mr. MONIZ. If I may just note, of course, the National Laboratories of DOE provide these tremendous user facilities that serve about 30,000 scientists per year, an example of something that would be totally impractical for individual universities, or companies. If I may add on the first question that I agree with the need for more resources. We have too many examples where the number of good proposals to available funds is such a large ratio that the—those selected are almost random, by definition, given the pull. We need that, but on the structure side, again, I would repeat two things. One is I am very concerned about some discussions going on about NSF somehow being commercialization driven. I think that would be a major slippery slope to get onto. And, secondly, there are areas, let's say in the energy area, where we have organizations that were put together to address the issue of oil embargoes in the 1970's, and do not quite reflect the technology-driven directions we need for addressing something like climate change.

Mr. FOSTER. Thank you, and I will yield back.

The CLERK. Mr. Meijer is next. Mr. Meijer, if you're ready, you're next. If not, Mr. Obernolte would be next.

Mr. OBERNOLTE. Thank you very much, and thank you to our witnesses. It's been an incredibly fascinating discussion on a very important topic. I'll direct my question to Dr. Arnold. And, Dr. Arnold, hello to my alma mater there in Pasadena. You, in your testimony, talked about the fact that portable fellowships would be a better way, perhaps, of investing in our future generation of talent, and I think that that's something I very much agree with, and something that I think would be a really interesting innovation, but I think it would cause some changes in disruption to the existing ecosystem that we have, where right now institutions, for better or for worse, kind of compete with each other for grant funding. And this would create an alternative system where institutions would compete with each other to attract these fellows. So can you talk a little bit about the pros and cons of shifting to that kind of a system? Because I find it a very interesting idea.

Dr. ARNOLD. What a great question, Representative. I'm at an elite institution that competes fairly well for NSF fellows. So there exists a program that provides portable fellowships, and we com-

pete very well. Some of the concern would be that all those portable fellowships will go only to those elite universities. But I don't think that will be the case. I think that we could triple, easily, the number of portable fellowships, and provide them more equitably than they are currently provided, and the students will choose the areas and the universities that meet their needs. These students know what the future will look like. These are the brightest students coming out of undergraduate institutions. They will create the future. They can choose whom to work for, which areas to work in, and so it really is a highly competitive way of distributing the funds.

Research grants are also good, but that structure, again, is much more set in stone. So professors like I am, we've been in place for 40 years, and many of us tend to do some of the same things, and don't move as quickly as the younger generation does. So if you really want to promote innovation, give it to the young ones.

Mr. OBERNOLTE. Well, thank you. I completely agree with you. In your written testimony I noticed that you also said that a lack of structure and hierarchy is key to promoting creativity, which is something I also agree with. You know, however, it has to be said that part of our job as legislators is to make sure that taxpayer funds are used for their intended purpose, and are used appropriately and wisely, and sometimes that's why we need hierarchy and structure. So, you know, when we get kind of, you know, these two ideas that are in tension with each other. And I wonder if you could talk a little bit about how that would relate to this idea of portable fellowships, because, you know, when we're talking about funding a student, and not funding a research project, we're really getting into more of an educational grant than a research grant. So how would we with these portable fellowships, how would we ensure that there's accountability?

Dr. ARNOLD. Well, of course, those grants are actually administered through universities, and I'm sure President Farnam Jahanian can discuss this as well. They're administered through a university, so you will have the same level of oversight of how the funds are spent. But instead of dictating the research area and the specific project they might work on—which I don't think is the role of the government—if we are going to foster creativity, we have to let the young scientists, the students, make the choice. And with this mechanism you are also funding individual scientists through the votes of the students, whose careers depend on that.

Mr. OBERNOLTE. Sure. I agree with you. I think there's probably a happy medium there where we choose promising fellows in areas that we want to increase investment in, such as artificial intelligence, or nanotechnology, or nuclear energy, and then, you know, we trust that we've chosen good people, and that they're going to follow their passion, so I think there's probably, you know, some happy medium there. But I think——

Dr. ARNOLD. That's a great idea.

Mr. OBERNOLTE [continuing]. It was a fascinating idea. I want to thank you for raising it, and thank you to all of our panelists. I think we all share a passion, as you do, for increasing investment in basic science in our country, and I want to thank you for being part of that effort. I yield back, Madam Chair.

The CLERK. Ms. Ross is next.

Ms. ROSS. Thank you so much, and this panel has been great. I'm from the Research Triangle area of North Carolina, and we have just amazing students there, and amazing institutions of higher education, and then, of course, a lot of innovation. I want to start out my remarks by highlighting an exceptional constituent of mine who is, I think, an example of innovation, and creativity, and drawing talent from other countries. Her name is Sepi Saidi, and she's a visionary leader in civil engineering, has a women-owned civil engineering firm. She is a champion of community service, went to NC State, and came to the United States from Iran, and contributed immensely to the STEM industry, and nurturing the next generation of engineers.

I wanted to ask Dr. Jahanian, since you've had a similar experience to my constituent Sepi, coming from abroad, becoming an expert and a leader in your field, and in your testimony you talked about the U.S. needing to better facilitate the ability of international students who earn advanced degrees in the U.S. to stay here and add to our talent development. This is vital to the universities in my district, and to the highly innovative Research Triangle Park, where there's a real pipeline from the institutions of higher education directly into the park. What can you advise these students as they look to advance their careers? We've taken some steps already this Congress for Dreamers, and for documented Dreamers, who came with their parents on H–1B visas, but what can you tell them about how to navigate our current system for staying in this country and being able to contribute?

Dr. JAHANIAN. Thank you so much for that question. And for sharing the story of a resident of your community, Sepi. I'm delighted to hear the stories. As you know, and I know other witnesses would attest to this, there are thousands, and thousands, and thousands of stories like this. International scholars make incomparable contributions to United States leadership in science, in innovation, in discovery, and many of them, the overwhelming majority of them, after they finish, want to stay here. In fact, you heard from Norm Augustine compelling data that 28 percent of U.S. STEM faculty were born overseas. Nearly half of the Fortune 500 companies were founded by immigrants and children of immigrants, including founders or co-founders of eBay, Google, and Moderna. These are amazing stories. Members of the National Academies are immigrants to this country.

I'm just going to be very candid, because this is also personal to me: we invest in these students to come here. They become part of our society. We should do everything we can to keep them. I think that has benefited us, without any doubt, over the past 75 years, certainly in recent decades, and I think it's been a recipe for success for our Nation. And I think the more we do to facilitate not only their success, but to make it easy for them to stay in this country and continue to contribute to the vibrancy of the economy that's based on science, and innovation, and technology, the better.

Students reach out to me, and I tell you, it's been stressful for many students, domestic as well as international students. COVID has had a dramatic impact on our students, their mental health, as well as on our doctoral students, in terms of the progress of

their work. So in the short term I know all academic institutions are doing what we can to support our students across the board at all levels, but with respect to the international students I'll go out on a limb and say we should stamp a green card on these students' diplomas when they finish in these areas that we have critical needs, and let them go into society and contribute to the vibrancy of our economy, and they will continue to play a significant role in the progress that our Nation makes in addressing significant societal challenges, as well as in innovation that catalyzes our economy.

I'm happy to take some of that offline and give advice to students in terms of how they navigate this, but, honestly, I think the responsibility is much more on us to create an environment to enable the success of all the students on our campuses. My humble recommendation to our policymakers is that we should make it easy for them to come and stay here. Thank you for that question.

Ms. ROSS. Thank you so much for your response, and we'll do the best we can. And, Madam Chair, I yield back.

The CLERK. Mr. Feenstra is next.

Mr. FEENSTRA. Well, thank you to each one of the witnesses for their testimony, and sharing their extensive research and opinions with each one of us. I'm excited to be an original co-sponsor, with Ranking Member Lucas's *SALSTA*, which helps create a long term strategy for investment in basic research and infrastructure to protect the economic and national security of the United States, and I really am excited about that bill.

I've got a question specifically directed for Dr. Augustine. Dr. Augustine, your publication on the perils and complacency, and your testimony mentions taxes and red tape regulations that hinder research and development carried out by universities, public and private partnerships. Can you expand on this a bit and explain which taxes or regulations are most limiting to this R&D, and then which would you advise reducing or removing entirely to prevent China from surpassing us in innovation?

Mr. AUGUSTINE. Well, thank you for that question. We have built many roadblocks. I'm aware of one study that shows that 40 percent of the time of our researchers is spent submitting reports, bidding on new projects, and administrative functions, as opposed to performing research, so that's a major thing. Another factor is the last time I was involved, the NIH awarded contracts to 17 percent of the qualified proposals they received, so in the rejection box there is an enormous amount of opportunity to be pursued.

And turning to taxes, one of the problems industry faces is the issue that the tax structure discourages long term investments, and I have a rather radical proposal that I've been making for years with little impact. Industry takes a very short term view of the world. The pressure's on for the next quarter from the marketplace. My proposal is to change the capital gains tax—I should qualify here, I'm an engineer, not an economist, but I am a rocket scientist. I would make the proposal that the tax on a gain, on an asset that's appreciated, the tax on the appreciation—if the asset is held 10 years, the tax should be one percent. If it's held one month or one day, the tax should be 99 percent. Then you could

draw whatever line between them—whatever revenue you need. That would change the way industry would behave entirely.

And I will just quickly tell a story that relates to this. When I was working in industry, our company decided to increase spending on research, and we sent the president of the company to Wall Street to tell what we were going to do because we were so excited about the opportunities we had in research. The audience from Wall Street literally got up and ran out of the room when our president finished talking, sold our stock, and our stock dropped 11 percent in four days. And we got the message, don't invest in research if you're in industry. The industry will invest in development, it has done so, but investing in research is not going to happen under today's tax laws and regulatory procedures. So thank you for the question.

Mr. FEENSTRA. Well, thank you for that information, Dr. Augustine. I just think it's so important that we have these public private partnerships, and we see that at our universities in the State of Iowa. And that's my last question I want to just quickly note, you know, private/public partnerships are crucial when it comes to American leadership in research and development, and one example in my district is the Critical Materials Institute, led by Ames Laboratory, which includes Iowa State University on its team. I'd imagine that the benefits and incentives that an academic institution assesses before agreeing to enter into a partnership would be different than those that a private industry assesses. Do both universities and private industries look for the same type of incentives to join these private/public partnerships, or there's differences? And I'd ask anybody on the panel that question. Any thoughts on that?

Mr. MONIZ. Well, yeah, I would just add, Congressman, for the specific example you put forward, I think right now there would be tremendous interest because the critical—critical minerals and metals, we are so far behind the eight ball on that it's crazy, in terms of the kind of supply chain focus that I mentioned in my statement that we need. So that's a critical example of bringing together public and private to address a serious supply chain issue, and raise some difficult questions. For example, can we develop environmentally sound mining to get back into domestic production? You know, the Ames Laboratory had a very, very critical role in the Manhattan Project, and that was based upon, of course, domestic mining, with different conditions than we need today. So that's a very, very important area, and the Ames Lab is doing a great job.

Mr. FEENSTRA. Thank you so much, and thanks for the time. I yield back.

The CLERK. Mr. Kildee is next.

Mr. KILDEE. Thank you, and I want to thank the Chairwoman for holding this hearing, and for really a stellar group of witnesses for your important, and I think really informative perspective, so thank you for your participation. Some of you know, because I mention it nearly every time I speak, that I come from Flint, Michigan, which, at the turn of the last century, was really one of the innovation capitals of the world related to the automotive industry. In Flint we helped put the world on wheels. If you drive around—in fact, if you drive around my hometown, you'll see streets named after some of these great innovators, Chevrolet, DuPont, who once

was the president—Pierre DuPont, once the president of General Motors, Dort. But, of course, due to pretty dramatic changes, technology change, globalization, disparate impact of trade policy, Flint, like lots of other older industrial cities, has lost parts of our manufacturing base.

But, you know, foundationally we have people with hard work, grit, determination. That's still intact, and we have access to great research universities. And Dr. Jahanian, you know one of them quite well, the University of Michigan. But, unfortunately, we haven't been able to make this connection to fully transition to the new economy, or especially to the new automotive industry. And I think, for example, we all know that electric and autonomous vehicles are the future of transit, of transportation and mobility, and it's important that we transition to these vehicles for safety, combatting climate change, improving mobility, et cetera, but in many ways we fear that much of the population is left out. So we can't stop this change, we don't want to stop this change, this is where the market is going, but I'm really curious about your perspective on how we make sure that we all share in this transition, in this transformation.

I'm working on Federal policy to help target investments to these older industrial cities, and so in the space of innovation and invention, I'm curious about how you think those connections are made. So perhaps starting with Dr. Jahanian, because you make reference to Pittsburgh, and how it made this transition from a steel and mining town to one focused on robotics and AI, a real center of innovation. What are the lessons, at least from your perspective, that you think could be applied to other older industrial cities trying to make this connection?

Dr. JAHANIAN. Thank you so much for that question, and there are so many layers to it. As I indicated in my testimony, one of the challenges we face in this country is that there is a widening opportunity gap, and that widening gap is exacerbated, in fact, by advances in technologies, by globalization, and barriers to access, and these are structural barriers to access and opportunity. I think it's an issue that many communities in the Nation face, and certainly I think Pittsburgh, long before I came here, was facing the same issue as a result of the decline of the steel industry.

I think Pittsburgh is a great success story, and has come a long way as a result of doubling down in education and research, and connecting that to the private sector, and creating an ecosystem that is catalyzed by not only these technologies, such as AI, and robotics, and autonomous vehicles, as you mentioned, but also by the sciences, and in recent years, as a result of resurgence of advanced manufacturing. So it's been very intentional, but the connection between the public sector and the private sector, and creative public/private partnerships, have been extremely important. It's not a self-serving comment, but the role that the university can play in expanding what I refer to as the geography of U.S. innovation is undeniable. We have extraordinary concentration of intellectual capital and capacity for ideas and discoveries that has to permeate and involve the community.

There's a lot more to say about this, but I want to acknowledge it's an important issue, and I think expanding this map would re-

quire us to make very targeted investment to create these innovation hubs around not just the universities, but also things that are adjacent to them, including incubation spaces, community and economic development entities that will essentially connect that technology transfer. It's not just the push from the university, but it's also the pull, and connecting all these pieces of the innovation ecosystem together. I hope that, at least at some level, scratches the surface in answering your question.

Mr. KILDEE. It's very helpful, I appreciate that. And I know my time's expired, but I do want to say that one of the weaknesses in communities such as this is that there has been an attrition in the public, and even in some of the business sector leadership because of the dramatic changes, and I think this is the space where academia can help fill some of that leadership capacity that's required. So, again, a great panel, I really appreciate all of your input, and I wish I had more time. I see Secretary Moniz might want to say something.

Mr. MONIZ. Could I add one comment? Which is that—just—as information for now, MIT and Harvard, with partners in Michigan, Indiana, and Ohio, we are looking at a case study of the transition from internal combustion engines to EVs (electric vehicles), specifically in that area looking at how the communities and the workers can be brought along in the transition, through supply chains and other methods.

Mr. KILDEE. Well, I would certainly want to follow up with that—with you on that, so thank you for that. Again, excellent panel.

The CLERK. Mr. Meijer is next.

Mr. MEIJER. Thank you, and thank you to our panelists for being here with us today. I represent Michigan's Third Congressional District. One of my predecessors, Vern Ehlers, sat on this Committee during his congressional tenure, and it was during that period that the first publication of "Rising Above The Gathering Storm" was published by the National Academies in 2007. So this congressionally requested report looked at improving K through 12 STEM education, developing and recruiting top students, engineers, and scientists from the U.S. and abroad, strengthening the Nation's commitment to funding basic research, and ensuring that the U.S. is the premier place in the world for innovation.

That seems to be exactly where we are right now, and with similar sentiments, so I guess my question for Mr. Augustine, and the broader panel as well, you know, this 2000 report seemed to have recommended just about the same actions that we're discussing today, in broad terms, you know, 14 years later. So I guess what—this is a bit of a compound question, but what, if anything has changed, you know, how should we take action to respond to these broader questions of competitiveness posed by the countries that are emulating our research ecosystem, and have been robustly investing in R&D?

Mr. AUGUSTINE. Yes, it's been about a dozen years ago that the first "Gathering Storm" report was prepared by the Academies, and, frankly, many of the problems that exist today are the same ones that we had pointed to at that time. There has been some progress made, much of it at the State and local level. I think there

have been encouraging signs. The thing that we did not recognize when we prepared that report was the speed at which China would move forward. My first trip to China was 44 years ago, and I saw a few automobiles, every adult was wearing a Mao suit. And I've gone back every half dozen years and seen what they have done, and it's remarkable. That's really the new ingredient here, China.

One recommendation that you provided me an opportunity to point to from the "Gathering Storm" report—or two, really—one was to increase the investment of basic research substantially. The other recommendation related to K through 12 education, and had to do with a lack of teachers available to teach in STEM. Not to just teach from the book, but to excite the kids about discovery and innovation. And that recommendation, if I can state it properly after all these years, was that the Federal Government should fund 10,000 competitively awarded scholarships to U.S. citizens to study science or engineering, with the agreement that they would teach at least 5 years at a public school after they received their degree. Today the average teacher only stays for 5 years, so the 5 year condition shouldn't worry us. Hopefully many of them would stay a lot longer than 5 years. And that would have a huge impact, I think, in enhancing our public school system. That probably was the most important recommendation of the "Gathering Storm" report that was not adopted, so thank you for the question.

Mr. MEIJER. Well, thank you. And I guess, you know, I appreciate you kind of filling in a little bit more on other opportunities we have to build on that. I certainly don't want us to be having the same conversation in another 14 years from now, talking about the same issues. But I guess I—you know, using that metaphor of the gathering storm, has that already passed, and are we in response/recovery mode right now because of that unforeseen, you know, explosion in R&D investment in China?

Mr. AUGUSTINE. The rate of progress of science and technology is just so immense it's hard to describe. A friend of mine who ran Intel a few years ago told me that 90 percent of the revenues Intel receives on the last day of any year come from products that didn't even exist the first day of that same year. That's the kind of a race we're in. Whether we're a year ahead or a year behind, it's hard to tell. The one thing that's very clear is that we're in the process of losing, and that China's got long term solutions. They've got their 14th 5 year plan. They've made very clear where they're going, and this Committee has the opportunity, I think to help America get on that same foundation. One thing I would caution—what is needed is continuity of funding, and of activity, and of actions. We've been through the shot in the arm, the doubling of NIH, the "shovel-ready" at the beginning of the Great Recession, post-Sputnik. What we need is continuity over time, and that would be, I think, kind of my bottom line, so thank you.

Mr. MEIJER. Thank you. Could not agree more, and I yield back.

STAFF. Ms. Wild is next.

Ms. WILD. Thank you so much, I appreciate it. And I thank you, Madam Chairwoman. I really appreciate this very timely hearing. I represent a district in Pennsylvania, and I'm so proud of the many researchers and innovators at Pennsylvania's companies and universities. I have Lehigh University in my district, Pennsylvania

7, and it's one of those that are charting the future of a clean energy and an America that still leads the world technologically. And in the House, I also serve on the House Foreign Affairs Committee. And as we confront significant threats from authoritarian governments around the world, I believe that collaboration with our democratic allies is a key to maintaining national and global security, and I think it has to include research collaboration that advances American innovation, and ensures international technology standards that reflect our democratic values.

And beyond maintaining those alliances, I believe it would be advantageous to global interests, and to accelerating innovation, to cultivate research partnerships with emerging economies and democracies. So my question first for Mr. Augustine is, what role does the international standard-setting process play in encouraging innovation in critical technologies? And Part B of that question is what steps should our government take to encourage American industry and stakeholder participation in international standards development?

Mr. AUGUSTINE. Another important question. China has recognized the impact of controlling the standards process. I would not argue that any one country should control the standards process, certainly it should be a collaborative effort to come up with standards. But it's a fact that to be first, and set the standards, puts you in the driver's seat, in terms of the marketplace. China is currently putting the effort in to be first in the standards area. That would be a significant topic for us to address. Of course, the National Institute of Standards and Technology plays an important role, as do organizations throughout the country that support NIST. Let's see. I forgot the second part of your question. What was Part B?

Ms. WILD. The second part was just what steps should the government take to encourage our American industry and stakeholder participation in standards development.

Mr. AUGUSTINE. Obviously, the government plays a leading role in this. Industry, I must confess, tends to be very self-serving, companies do, and I think that this is one of those roles that it takes government to kind of pull things together.

So the beginning of your question, I think it was such an important point that the United States has one huge advantage over China, and that is our allies. We can work together with our allies, whether it's standard setting, or sharing research results, or educating each other's students—just as an example, if you take the United States and just two of its allies, Europe and Japan, they comprise a little over 50 percent of the world's GDP. If you take China and its three putative allies, North Korea, Iran, and Russia, combined, they're 17 percent of the world's GDP. So one of our huge advantages is to work with our allies to build alliances. Share students, share teachers, share knowledge. And I'm so glad you raised the question.

Ms. WILD. Thank you so much. Madam Chairwoman, I can't see the clock on the screen. I'm not sure if I have more time or not.

Mr. BEYER. You have another minute, Susan.

Ms. WILD. Thank you so much. I have a question for Dr. Moniz. Given your previous experience leading the Department of Energy, as we aim to develop and apply critical technologies to tackle global

issues, how can policymakers leverage existing international research partnerships, and cultivate new ones, with emerging global economies?

Mr. MONIZ. Thank you, Congresswoman. Let me first add one footnote, if I may, to the discussion you had with Norm, namely that from the other point of view, namely foreign relations and geopolitics, I think we've made a major error in dialing back on scientist to scientist collaboration with our adversaries. Because, during the cold war, for example, those relationships were absolutely critical when the, you know, Iron Curtain came down, in effect. So I think we need to use a lot more of that kind of collaboration as well for our own geopolitical and foreign policy objectives. In terms——

Ms. WILD. Thank you for that perspective. I agree.

Mr. MONIZ. Yeah. In terms of the—your question, well, again, in the—if I stay to the energy arena, as I said earlier, we have a vehicle, frankly, we were the drivers of setting it up, the so-called mission innovation. It's not—it's 24 countries, allies, and less clear perhaps in that spectrum there, all committed to increasing the innovation pipeline, all committed to collaboration. Every thrust is basically jointly led by countries, and some of it is surprising. For example, early on Mexico took the lead in mission innovation to work with the United States and Canada to set up high throughput novel materials by design for energy technology cooperation. We chair, with Saudi Arabia, an initiative on carbon capture and sequestration (CCS). But frankly, it needs more juice. And as I said, now, with a new administration, rejoining Paris, we should go in now and take the bull by the horns in terms of revitalizing and expanding mission innovation into new areas. I mentioned nuclear, I mentioned carbon dioxide removal, for example, but we have a——

Ms. WILD. Thank you.

Mr. MONIZ [continuing]. We have an opportunity waiting for us.

Ms. WILD. Thank you so much. I yield back.

Mr. BEYER. Thank you. Mr. LaTurner is next.

Mr. LATURNER. Thank you, Mr. Chairman. This question's for everyone. I believe there's a need to prioritize federally funded basic research, which is one of the goals of *SALSTA*. I have concerns about the proposals coming from the administration and Senator Schumer that will most likely be funded through reconciliation as a one-time money dump at levels that aren't sustainable in the long term. You have all testified to the importance of basic research, but if you could, in just a few words, can you comment, each of you, on how long term sustained growth in basic research funding would help the U.S. remain the global leader in innovation, and the threats of volatile, unstable funding, the threats that unstable funding may have on the U.S. research enterprise?

Mr. AUGUSTINE. I'll start, if we're going in alphabetical order, if that's all right. The——

Mr. LATURNER. Thank you.

Mr. AUGUSTINE. I'll speak of the importance of continuity of research and development. Most research projects, from the time they begin until they produce something in the marketplace, you're talking about—on the order of a decade. Some are faster, some are slower, but it's certainly not the next quarter, or the next year, or

the year after that. One concern is having an adequate amount of funding, and the second is to sustain it over time, and either one without the other leaves a rather hollow core. It would be my strong opinion that we should commit to a long term sustaining of growth. That also sends a signal back to young people. When you get these spikes that disappear, and all of a sudden there are jobs then there are no jobs, young people see that, recognize it, and they say, "That's not a field I want to go into because it's too turbulent." So that would be my comment, and I'll stop there so my colleagues have time.

Mr. LATURNER. Thank you.

Dr. ARNOLD. I agree. It's the volatility that's extremely harmful because, again, the best people have multiple choices, and they'll go to more stable or enjoyable careers. Basic research takes a real commitment to do it, and if the funding does not make an equal commitment, then we lose the best.

Mr. LATURNER. Thank you.

Mr. MONIZ. Perhaps I will just add to that, that—and I won't repeat the volatility issue, but, as I said, I believe we need to really—you said prioritize. I think we really need to keep in mind the broad base of fundamental research as so important. Examples are myriad. I'll just mention one. GPS (Global Positioning System) is now so ubiquitous we hardly even talk about it anymore. Where did it come from? It came from people bringing together progress in communications, in satellites, and the atomic clock that was invented to test Einstein's Theory of General Relativity. Nobody was planning on a GPS system when that happened. So we can afford it, and we, in fact, can't afford not to, in my view, support this broad base of fundamental research, even as we then advance in addition toward the use-inspired research that will spill out all over the place into commercial products.

Dr. JAHANIAN. I'll be very brief. You know, the process of innovation discovery is often marked by long, unpredictable incubation periods between the initial scientific discovery and the societal and economic impact that we see. In fact, sustained investment in basic research is so important because we can't predict the outcome. Some of the most important discoveries that we have made that have made fundamental advances and contributions to the well-being of society, to our economic prosperity, were not intended initially, in their most foundational stage of investment, to have that outcome. It's the unpredictable, unanticipated outcomes that are a result of sustained investment that often have the most impact. We have seen this in a broad range of technologies and industries, from the internet, to semiconductor technologies, to advanced materials, to nanotechnologies, and so on. So for that reason I think sustained investment is very important.

Secondly, I want to echo what Ernie Moniz said, which is that, while we're talking about foundational research, we need to understand that investment in the entire continuum has to continue. Furthermore, at this particular moment, there are a set of technologies that are pervasive, and they're having disproportionate impact on everything else, including AI, robotics, biotechnologies, and wireless, and so on, and we can't lose focus that those targeted investment have to happen in addition to the investments that

we're making in all areas of scientific inquiry. Thank you again for that question.

Mr. LATURNER. Thank you so much for all of your answers. I yield back.

The CLERK. Mrs. Fletcher is next.

Mrs. FLETCHER. Thank you so much. Thank you to Chairwoman Johnson, and Ranking Member Lucas, for holding this hearing today, and thank you to the witnesses for testifying. I really appreciate your perspectives on our investment in our people, and in our research, and the things we need to do moving forward, and I also very much appreciate the important work that you do, Dr. Jahanian, Dr. Augustine, Dr. Arnold, you are an inspiration and a role model for many, especially the women in science who—many of whom live in my district, because I represent Houston, Texas, where we have a ton of innovation, and a ton of really critical research going forward. And, of course, I am focused, as they are, on energy innovation in particular.

So I want to take the opportunity to start my questions with Dr. Moniz, and I really appreciate the comments that you just made, Dr. Moniz, about carbon capture, utilization, sequestration. I agree that that is really important. We passed important bills out of this Committee, and out of the House last year, trying to make sure that we are investing in that. I wanted to take this opportunity, while I have you here, to ask you a little bit about hydrogen, because hydrogen is currently enjoying unprecedented political and business private investment momentum, with the number of policies and projects in the world expanding, as I understand it, rapidly. Houston is home to 48 plants that extract hydrogen from natural gas, and produces more than a third of the United States' supply of hydrogen. Several sectors have concluded it's really important, and timely, and pertinent for the U.S. to scale up technologies and bring down costs to enable hydrogen to become more widely used. So I would love to get your thoughts on what further technology innovation is needed to bring down the cost of hydrogen, and specifically hydrogen produced from clean energy sources.

Mr. MONIZ. Thank you, Congresswoman. Hydrogen—we're—we are certainly very, very bullish on—as a very important innovation direction, and a reason for it, just to—I mean, you're aware, but perhaps others may not be, that—the thing is that hydrogen, in a certain sense, like natural gas, is—can play the role of a fuel in multiple sectors, from power, to industry, to transportation, and the like, so it could be—it could play an absolutely critical role.

We think that there are many places in the country, and you'll be pleased that, of course, Texas is obviously one of them, where we can see major hubs developing around both hydrogen and CO_2 management at the same time. And the reason for that is, while there is a lot of discussion about so-called green hydrogen, electrolysis of water, which we think will be playing an important role in the future, innovation is needed to both reduce the electrolyzer costs—it's like battery costs, et cetera, that have to come down in time—and innovation that will provide the electricity system to produce very, very low carbon, very inexpensive electricity to drive green hydrogen. But we believe there is also a major opportunity for blue hydrogen, which, as you said, is extracting hydrogen from

methane, which is mostly hydrogen, but then capturing the carbon dioxide and sequestering it underground, where, of course, also Texas has got lots of experience. And right now blue hydrogen is certainly substantially less expensive than green hydrogen.

So a big issue here is the co-development of the infrastructures for hydrogen utilization and for large-scale CO_2 management. And Texas, and many other places, by the way, the upper Midwest, the Appalachian region, there are many places in the country with also heavy industry that can go clean in this direction.

Mrs. FLETCHER. Well, that's great. Thank you so much, Dr. Moniz. And if I can just follow up on that, because you mentioned sequestration, and kind of the Texas geology being, you know, particularly useful. There's another thing that I've been hearing lately about our geology, and I've got 30 seconds left, so I just will follow up with you on your thoughts about geothermal energy as well.

Mr. MONIZ. Well, geothermal energy, if it can be developed at scale, particularly so-called engineered geothermal systems, that has the enormous advantage of being a dispatchable renewable source, in contrast to wind and solar, where, of course, we have major storage issues that need to be handled, and reliability issues, grid integration issues because of the variability. But all of these can come together into a reliable and resilient system as we go forward. We need innovation. For example—OK, one more thing. In Texas, for example, we looked at wind resources for a year, hour by hour, and what we found were there were as many as nine days in a row with no wind, essentially, in the State. So that just reinforces we need not just batteries, but long duration storage and integration with other sources so that the system is always reliable and resilient.

Mrs. FLETCHER. Well, thank you for that. I agree, we need a diversity of fuel sources, and it's really important for us to understand the science of our energy, so I really appreciate you being here. I appreciate all of your testimony, and your written testimony. I've gone over my time, so I'm going to yield back, but thank you——

Mr. MONIZ. But I'm going to add one more thing. It's very important. Many of these approaches, CCS and engineered geothermal, what's very important, they will also draw upon the skillset of the oil and gas industry, and so this can be an enormous continuity of workforce issue as well. Sorry.

Mrs. FLETCHER. No, thank you, Dr. Moniz, and I yield back. Thank you.

Mr. BEYER. Thank you, Lizzie, very much. I'm Don Beyer, and I'm batting cleanup, but first I want to thank all of you for hanging in there for 3 hours. I hope you're at your home or your office, but you've been very patient, and very brave and resilient. And let me just begin—Dr. Arnold, you—I'm going to quote from your testimony. You said, "It was easier, however, 35 years ago to start a career in academic research. We didn't spend 2/3 of our time at department meetings, writing proposals, or making"—"we were complying with regulations. Instead, we focused on"—"that has degraded." Why, or how do we fix—how do we reform the university? Because this is not the first I've heard that complaint, that you spend all your time in committee hearings.

Dr. ARNOLD. Yes. Well, it's not entirely university's fault, right? The size of the typical grant from the National Science Foundation, for which I am hugely grateful, supports at most one student, and often research group have several students, so that means that, with these very small grants, we're always just writing. And then with—along with each grant, the compliance is very complex. Financial compliance, research integrity, everything is very complex, and we often don't have a lot of support. So the university can help by providing the support, but, of course, that's complex for the university, and expensive. We're—we end up doing a lot of things we're not very good at, and it way—and it uses our time in a way that takes us away from our chief mission. There has to be some better distribution of some of these responsibilities.

Mr. BEYER. OK. By the way, we're all very proud of you, as the first woman to—first American woman to win the Nobel in Chemistry. It's very cool, inspiration to my three daughters.

And I really want to thank Mr. Augustine and Dr. Moniz for your leadership on fusion energy. We've actually stood up a bipartisan fusion energy caucus here on the hill. Had a couple meetings already. And, Dr. Moniz especially—when I talked to my pals at MIT, they said fusion energy, which has been 25 to 50 years away every year for the rest of our lives, is now maybe 5 years away. And the National Academy of Sciences—or National Academy came two weeks ago and said, you know, the first power plant could be ready by 2035. And yet our private sector folks, people like Key A and Conwell Fusion think must faster. Where what—what's—where's reality lie, in terms of commercial delivery of fusion?

Mr. MONIZ. Well, first of all, I think the—as I said earlier, the 5 years which are being quoted by those two companies, and by other companies as well, with novel fusion approaches, it really is that within 5 years we think that the—we'll have an answer, yes or no, that the scientific challenges required for a fusion power plant will be resolved. If that is resolved—we're optimistic, but if it's resolved positively, I think it's—personally, and some of my colleagues on the board may argue with me, but I think it's—in the real world it's got to be at least 10 years to go through the engineering, the licensing, the building, the capital raise, to get a power plant.

But if we have power plants based on that technology that are coming out in 2035, or even 2040, it is a just—as I said earlier, a total game changer for where we go with clean electricity, including a game changer on how you would design the grid infrastructure. Because having a large number of very small footprint, high output dispatchable low carbon power is very, very different system design to having, you know, very, very low energy density spread out far from load technology. So it's going to be——

Mr. BEYER. So——

Mr. MONIZ [continuing]. It's going to be interesting.

Mr. BEYER. So it would all have to be in Texas, right? So—but the other piece of this—I can talk to you—I've got a bill on air capture, you know, of carbon, and of course the dilemma there is we have to turn it into a refundable tax credit because there's not much you can do with it. We're basically going to have to pay the private sector to take it out. So what I'm told is that the only en-

ergy source as plausible to pull the carbon out of the air is going to be fusion.

Mr. MONIZ. Well, I don't know. We'll see about that. There are many other approaches going. What I would like to emphasize, Congressman, is that direct air capture is one of many, many routes towards removing CO_2 from the atmosphere, including terrestrial approaches. Some of them involve biology, like new plants with very, very deep root systems. The Salk Institute actually is developing that kind of technology. Mineralization technologies. There's really a big portfolio, and I—what I would urge is significant support across this broad portfolio. We estimated that roughly $10 billion over a decade would bring a huge number of those different technology pathways to commercialization in a decade.

Mr. BEYER. So I—this is good time for a shoutout for the Land Institute in Salina, Kansas that's working on food sources for perennial plants, so you——

Mr. MONIZ. Uh-huh.

Mr. BEYER [continuing]. Get those deep roots——

Mr. MONIZ. Yeah. Yeah. Yeah.

Mr. BEYER. And one last comment. I know my—Jake LaTurner, the Congressman, brought up the idea of the long term commitment to research funding, so it doesn't go up and down. And, of course, we hear from the National Science Foundation, NIH, et cetera, the shrinking number of excellent projects that are approved because of this. The only way to—since one Congress can't commit the next Congress, the only way to do this is through so-called mandatory spending. Dr. Moniz, you were a lead bureaucrat, Secretary of Energy, how do you think we could actually get mandatory spending for R&D into the budget?

Mr. MONIZ. That was a pejorative description of my job, but—no—well, let—I mean, I'll just speak again from the energy area, there are a variety of ways it's been done. For example, about 15 years ago, maybe, there was a—Congress approved for 10 years a fraction of oil and gas royalties paid to the Federal Government would go into an R&D program for—in that case for unconventional natural gas. So there's an example of the kind of thing which could be done. Earlier there was also a discussion of—for example, if you—as one example, if you had a one mil per kilowatt hour charge on all electricity delivery going into R&D to manage CO_2, that would be $4 billion a year. One mil per kilowatt hour, which would be, you know, well underneath the fluctuations in the electricity bill. So I think there's—I'd love to talk with you, if there are some options for moving legislatively to create a mandatory funding stream, for energy and for other areas.

Mr. BEYER. Thanks. We've been working for a number of years on just a House resolution, which is a sense of Congress, that is should increase 4 percent per year.

Mr. MONIZ. So——

Mr. BEYER. We will definitely——

Mr. MONIZ. OK.

Mr. BEYER. Well, look, it's one o'clock. I'm so grateful for you guys. I think you've heard from Democrat and Republican for the last 3 hours how fascinating this has been, and I could take another hour, but I'm not allowed to. So I just want to formally say

that we bring this hearing to the close, that we very much thank you for your testimony, for all your wisdom, for your experience. The record will remain open for two weeks for additional statements from Members, and for any additional questions the Committee may ask of the witnesses. And, with that, with my Zoom gavel, I declare this hearing over. Thank you very——

Mr. MONIZ. Thank you all.

Mr. BEYER. Thank you.

[Whereupon, at 12:59 p.m., the Committee was adjourned.]

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