S. HRG. 116–244

THE STATUS AND OUTLOOK OF ENERGY INNOVATION IN THE UNITED STATES

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED SIXTEENTH CONGRESS

FIRST SESSION

FEBRUARY 7, 2019

Printed for the use of the
Committee on Energy and Natural Resources

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CONTENTS

OPENING STATEMENTS

WITNESSES

ALPHABETICAL LISTING AND APPENDIX MATERIAL SUBMITTED

THE STATUS AND OUTLOOK OF ENERGY INNOVATION IN THE UNITED STATES

THURSDAY, FEBRUARY 7, 2019

U.S. SENATE,
COMMITTEE ON ENERGY AND NATURAL RESOURCES,
Washington, DC.

The Committee met, pursuant to notice, at 9:37 a.m., in Room SD-366, Dirksen Senate Office Building, Hon. Lisa Murkowski, Chairman of the Committee, presiding.

OPENING STATEMENT OF HON. LISA MURKOWSKI, U.S. SENATOR FROM ALASKA

The CHAIRMAN. Good morning, everyone. The Committee will come to order. It has been a busy week here on the Energy Committee with our Lands bill that is currently on the Floor. We had a business meeting a couple days ago, and now we are here for our second full Committee hearing. So we welcome those of you on the panel this morning.

On Tuesday, we heard from those in the energy and minerals market an overview looking at the current trends. Today we are going to look at what is happening to drive the energy trends of the future, what could be the next breakthrough energy technology. We use the term "breakthrough" a lot. Let's try to define that a little bit this morning. We are also looking to how we can encourage innovation that will deliver better, cleaner and cheaper energy for American families and businesses.

Here in the United States we have long been on the cutting edge of energy innovation. Whether the battle for electric current supremacy between Nicola Tesla and Thomas Edison, the invention of the semiconductor or the revolution in hydraulic fracturing, American ingenuity has led the way in global innovation, but we want to continue to lead the way in global innovation.

Underpinning all these efforts is strong support for the basic sciences and the people who dedicate their lives to furthering scientific pursuits. The Department of Energy plays an outsized role in pushing the limits of basic science, furthering discovery and finding the breakthroughs that can change our energy future, and they further leverage this by partnering with private industry and the great researchers at our nation's universities.

Our role here in the Congress is to help foster an environment that encourages that innovation. Last Congress we enacted a number of important innovation policies into law, ones that promoted a national quantum initiative, advanced nuclear energy and energy efficiency. But looking forward, we also know that the energy challenges facing us here in the United States and the world will require bigger, bolder, better, brighter, faster, smarter ideas.

I have often spoken about clean energy innovation policies as "no-regrets" solutions, but in reality, these are just the first steps. It is time to push hard to bring down the cost of clean energy, technologies like renewables, advanced nuclear and next-generation energy storage and carbon capture. If we want credible technological solutions that are cost-effective and deployable globally and at scale, we must ensure that the policies that we put in place propel these forward.

I am pleased to welcome a very distinguished panel of witnesses that we have before us. From the Department of Energy (DOE) we have the Under Secretary for Science, Paul Dabbar. Thank you for being here and for your work that you are doing to further the basic science research and the innovation that goes on at the department. We appreciate that.

Next we have someone who is truly a friend of the Committee. We have seen him in different capacities here. Secretary Moniz is a former Secretary of Energy. We welcome you back to the Committee and appreciate the insight that you will provide and what you will be able to share with us with this recent report that is out. It was a pleasure to be able to visit with you and Mr. Yergin yesterday to get some of the low-down there. So thank you and welcome to the Committee.

We have Jay Faison who is with us this morning with ClearPath. Jay has been a real leader in so many of these clean-energy solutions and how we advance those benefits, so it is good to have you back with us.

From the Council on Competitiveness, we welcome back its President and CEO, Deborah Wince-Smith. It is good to have you here.

Jason Grumet has, again, also been before the Committee many times and is a good strong voice on so many of these issues, but he is the President of the Bipartisan Policy Center.

And then finally from the fantastic little state—Senator Manchin is always saying "my little State——

Senator MANCHIN. Compared to Alaska.

The CHAIRMAN. ——of West Virginia." Yes, we are good with that. But it is wonderful to have you here, Mr. Wood. He is the Interim Director of the West Virginia University (WVU) Energy Institute. It is a pleasure to have you with us here this morning.

With that, I turn to my Ranking Member for any comments that you may have.

OPENING STATEMENT OF HON. JOE MANCHIN III, U.S. SENATOR FROM WEST VIRGINIA

Senator MANCHIN. Let me say thank you, Chairman Murkowski, for convening this hearing to discuss how we develop, test and commercialize breakthrough energy technologies and to have all of you. This esteemed panel is really special.

This hearing is particularly important because innovation is a critical piece of how the Committee can contribute to the pursuit of technological energy manufacturing solutions that will help reduce carbon emissions and address climate challenges.

The Breakthrough Energy Report that was released yesterday has some ideas I think this Committee should consider. Senator Murkowski and I had a robust discussion with Secretary Moniz last night, and I look forward to continuing that today.

I am especially pleased to have my friend, Jim Wood, here from the West Virginia University Energy Institute to talk about the cutting-edge solutions that WVU is working on today. Much of WVU's good work is in partnership with the National Energy Technology Lab, both mainstays in the Morgantown, West Virginia, area and leaders in finding ways to burn coal and natural gas in a cleaner, more efficient way. As I said in our last hearing, my home state, my great little, compared to Alaska, home State of West Virginia, is committed to solving the climate crisis. Breakthrough technologies will help us reliably meet our energy needs in the future while decarbonizing our energy system. Now as we think about affordable and reliable electricity, we must acknowledge that fossil fuels will continue to play an integral role in our electricity generation. With that in mind, we need to prioritize the advancement and commercialization of technologies, like carbon capture, that we can employ both here at home and overseas.

In 2017, China and India used coal for 67 and 74 percent respectively of their electricity needs. While I understand both countries are taking steps to reduce emissions and add more renewable generation, fossil fuels are still a part of their future, and ours. By 2040, the International Energy Agency says China will still be about 51 percent dependent on coal and India will be 57 percent.

Dr. Jesse Jenkins and Samuel Thernstrom recently wrote in the New York Times that if we are going to decarbonize our economy, we must do so with more than just wind and solar. They concluded that it would be much cheaper to include so-called firm, low-carbon technologies such as nuclear, carbon capture, or reliable renewables like hydro than it would be to build a clean-energy system without them.

So it is time to seek out practical solutions for emissions and ways to strike the balance between energy, the environment, and jobs. A large part of finding that balance is strengthening our investments in advanced R&D, which we will talk about today, for carbon capture, utilization, and sequestration (CCUS) and making coal plants more efficient. It also means investing in advanced nuclear technologies that make the current nuclear fleet more cost-effective while moving the ball forward on small modular reactors. That is going to take a lot of private capital from leaders such as Mr. Bill Gates, but it will also require even more leadership from the Federal Government.

Then there is energy efficiency. As we heard from the panel at Tuesday's hearing, energy efficiency really is the low-hanging fruit. The DOE estimates that efficiency improvements can save U.S. consumers and businesses 741,000 gigawatt-hours of electricity between 2016 and 2035, which is equal to 16 percent of the electricity used in 2035. That is a tremendous energy resource. That is a potential cumulative savings of 6.5 gigawatts in my great little State of West Virginia alone by 2035.

But it is not just about efficiency savings in buildings, it is about what technologies will make electricity transmission in particular more reliable and more efficient. So I am interested to hear from this panel on the level of investment there and what the ongoing regulatory challenges are to reducing those losses in the line.

That brings me to storage. Whether we are talking about batteries or pumped hydro, there is a lot of good work going on about how we approach energy storage, but we do not have the magic answer yet. So let's talk about the timeline and how we get there and how we can do it in the interim to ensure the lights stay on, homes stay warm, and businesses keep running. We need cost-effective technologies and solutions that make us productive and competitive in a global market while allowing us to lead on climate solutions.

We have an esteemed panel here today, and we are eagerly waiting to hear from you all to give us the answers we need.

Thank you very much.

The CHAIRMAN. Thank you, Senator Manchin.

I think we have introduced folks in terms of a little bit of your background, so let's just begin the testimony here this morning. We will begin with you, Under Secretary Dabbar. I would ask that you try to keep your comments to about five minutes. Your full statements will be included as part of the record. Again, we are very, very pleased to have such a well-rounded and distinguished panel. Please proceed.

STATEMENT OF HON. PAUL M. DABBAR, UNDER SECRETARY FOR SCIENCE, U.S. DEPARTMENT OF ENERGY

Mr. DABBAR. Thank you, Chairwoman Murkowski and Ranking Member Manchin, for the opportunity to come and discuss the nation's energy innovation cycle.

Before I begin, I'd like to thank Secretary Moniz and Deputy Secretary Poneman for their stewardship of the Department and the national labs. The Department holds the legacy of innovation that helped win World War II and the Cold War. Fermi and Lawrence, Rickover and Oppenheimer combined brilliance with action. I submitted to this Committee a copy of the 75 Breakthroughs of National Labs which summarizes some of the top innovations that have come out of our national lab complex since their start.

We also submitted our new policy paper, American Scientific Leadership for the 21st Century, and it's also on the DOE website. In it, we highlight our policy positions on execution and federal support for discovery. We highlighted the six exciting areas which have the possibility of truly transformative opportunities for humankind: artificial intelligence, quantum technologies, advanced and sustainable energies, space and the universe exploration, advanced mobility, and genomics. Major breakthroughs in these areas are in our grasp, and we are proud of the role the DOE has in advancing them. The American energy technology revolution driven by the national labs, universities and the private sector has dramatically improved emissions, costs and energy production. There has been significant increase in policy proposals as of late around mandates and taxation to drive energy and emission goals. These positions are being driven without full understanding that the labs and the market have driven significant jumps in energy technologies. Wind turbine capacity factors have increased by more than 50 percent. Solar costs have dropped by more than 90 percent. Utility-scale batteries are now cost competitive with gas turbines without incentives. Gas turbine heat rates, which is an efficiency factor, have dropped by more than 10 percent, and it's hard to get thermo to move 10 percent. Oil and gas cost improvements have dropped prices by over 60 percent. Our costs, energy production and emissions have dramatically improved because of American innovation driven in part by broad bipartisan support for the national labs.

What is on the horizon for American innovation for energy? Research will continue to deliver significant reductions to emissions and costs. There will be significant jumps in technologies including battery chemistries three to five times better than lithium-ion; carbon capture based on new materials; next generation nuclear; and, distributed grid technologies. And there are three private fusion companies looking to build their first power prototypes including one that Secretary Moniz sits on the board of.

We are also committed to the policies that support commercialization to combine the expertise of the labs with the energy of the private sector to speed the movement of technologies to the marketplace. For example, in November we launched the laboratory agreement and liability reform initiatives to streamline our labs' abilities to enter into partnering agreements. These will significantly reduce the efforts for commercialization.

The DOE is co-leading the Administration's lab-to-market goal with the focus on reducing execution burdens, increasing private sector engagement and building a more entrepreneurial workforce, R&D workforce. We have designated the Director of the Office of Technology Transitions as the Department's Chief Commercialization Officer, which elevates the status of driving DOE technology. We also just established a Research and Technology Investment Committee implementing the requirements of the DOE Research and Innovation Act that was passed this last year. This Committee will convene R&D elements of the Department to coordinate research priorities, cross-cutting opportunities and ensure the key decisions are leveraged. These actions we just took are in alignment with the Breakthrough Energy Report that was just submitted this week.

Additionally, DOE has kicked off a series of summits called InnovationXLab. The XLab summits increase lab engagement with industry, investors and customers in which we both highlight the research from the national labs that is approaching commercialization application but also hear from industry about its interest and its investment criteria. In this way, we incorporate market pull as an important part of our R&D planning portfolio.

As a part of this, I'd like to kindly ask the Committee for consideration at one point around the leadership positions that are still open for us as a Department. We very much appreciate the leadership of this Committee on reviewing our nominees, but we still have the heads of the Office of Science, ARPA-E, as well as General Counsel on Nuclear Energy. We kindly ask for potential full Senate consideration should the nominees be voted out of this Committee again.

So thank you very much.

[The prepared statement of Mr. Dabbar follows:]

STATEMENT BY
THE HONORABLE PAUL M. DABBAR
UNDER SECRETARY FOR SCIENCE
U.S. DEPARTMENT OF ENERGY
BEFORE THE
SENATE ENERGY AND NATURAL RESOURCES COMMITTEE
ON
THE STATE OF ENERGY INNOVATION
FEBRUARY 7, 2019

Thank you, Chairman Murkowski, Ranking Member Manchin, and Members of the Committee. I am honored to discuss the state of our nation's energy innovation.

Before I begin, I and the rest of the current DOE leadership team would also like to extend a special thanks to Secretary Moniz, as well as Deputy Secretary Poneman, for their outstanding leadership of the Department and their exceptional stewardship of our National Laboratories. The National Laboratory Complex (Lab Complex) was created long before we were born, and will continue long into the future after we are all gone. And it is incumbent upon us in leadership to commit to these institutions, add to them, and help accomplish a part of their lifetime of missions, and hand them off to the next leadership team a bit stronger. We say thank you to the previous team, for the strong current state of the National Labs.

As Secretary Perry noted at Secretary Moniz's portrait unveiling this past fall, from the first Secretary of Energy James Schlesinger to Secretary Bill Richardson to today, this Department has grown in stature and importance in serving our nation in driving innovation.

The Department's innovation enterprise consists of more than 60,000 people in program offices, across the Lab Complex, and among the researchers across the country at universities in all fifty states supported by our grant programs. The Department has benefited from the bipartisan support we have received for more than four decades.

The Department holds the legacy and mission-driven science and innovation that helped win World War II, and then helped keep the peace in the Cold War. Fermi and Lawrence, Rickover and Oppenheimer, as well as the others who followed, were individuals who combined brilliance with a bias for action. Their profound impact, beyond science and innovation, includes protecting and strengthening the economic and national security of our nation.

Today, the talented and dedicated individuals who serve at the Department are proud to be part of that tradition, and even prouder to still serve that mission. One of the most noteworthy examples of the impact of our individuals is that the Lab Complex is the greatest generator of Nobel Prize Laureates in the world, with over 40% of the prizes in physics, and over 25% of the prizes in chemistry, awarded to people who have worked in our National Laboratories.

This last week, I posted our policy paper, "American Scientific Leadership in the 21st Century," and we submitted that paper also to this Committee for this hearing. In it, we highlight the importance of federal support for science and innovation, as well as our focus areas for FY 2019. I also submitted to this Committee a copy of the "75 Breakthroughs" of the DOE National Laboratories that summarizes some of the world's top innovations discovered or supported by our National Laboratories.

I will identify six areas of special interest today: Artificial Intelligence, Quantum Technologies, Advanced and Sustainable Energies, Space and the Universe Exploration, Advanced Mobility, and Genomics. And we at the Department, with your significant support over the years, are taking a lead on all six of these areas.

Within the areas of innovation, I will segment our research into two areas: Applied Energy and Science, and discuss some of our innovation research efforts.

Applied Energy:

The American energy revolution, driven by the National Laboratories, universities, and the private sector, has dramatically improved emissions, costs, and energy production in the last decade. And this technology revolution is based on American innovation.

In the last decade, there has been a significant increase in public policy proposals with mandates or taxation for energy to drive energy and emissions goals. These positions are being driven without full understanding that there has been a very significant jump in energy technologies.

The following are some of the dramatic technology jumps that have occurred in the past decade:

- Wind turbine capacity factors have increased by more than 50%[1]
- Solar all-in production costs have dropped 90%[2]
- Utility-scale batteries are now cost competitive with natural gas turbines[3]

Our costs, energy production, and emissions rates, have dramatically improved because of American technology innovation, driven by broad bipartisan support for federal research at the National Laboratory Complex, as well as in academic institutions and the private sector.

What is on the horizon for American Innovation for energy?

We believe that U.S. scientific research will continue to deliver significant reductions to emissions and costs as replacement cycles drive modification or replacement of older plants with newer technologies, whether in fossil, nuclear, or renewables.

[1] https://www.energy.gov/eere/wind/downloads/2017-wind-technologies-market-report
[2] https://www.seia.org/research-resources/solar-market-insight-report-2018-q4
[3] Vistra West Texas battery, 375-megawatt Visra Moss Landing battery, 182.5-megawatt Tesla Moss Landing battery

There will be significant jumps in new energy technologies, such as new battery chemistries three to five times better than lithium ion, carbon capture based on just-developing new materials, and next generation nuclear. New distributed grid technologies to integrate these are moving fast. And we expect to become a net energy exporter, and expand our leadership in energy technologies globally.

Battery storage is a great example of a key technology that millions of people see, need, and want to use.

Increasing electric vehicle ranges, portable device battery lives, and optimal use of renewable and fossil power sources – such as harvesting daytime solar power for use through the night – are possible with improved chemistry, materials, and manufacturing processes that DOE's National Laboratories are pursuing.

Battery recycling also gives us an opportunity. Lithium-ion batteries are currently collected and recycled at a rate of less than five percent, which is why we recently announced the launch of a Lithium-Ion Battery Recycling Prize and the establishment of an associated Battery Recycling R&D Center. Through those efforts, we hope to profitably capture 90 percent of all lithium-based technologies in the United States, making an impact not just in battery storage but also critical materials.

I would like to highlight renewables and grid modernization, as a second area of Applied Energy high-impact research.

Grid modernization was the focus of our most recent Innovation XLab event, and with our National Laboratories, we're conducting innovative research and development designed to move us toward a stronger, more reliable North American energy system.

There are five priorities driving those grid modernization efforts:

1. Developing a dynamic North American Energy Resilience Model to understand risks to infrastructure and identify potential investments to be made by asset owners;
2. Exploring opportunities to improve the resilience of the transmission assets that feed critical sectors, particularly for defense-related infrastructure;
3. Supporting the development of sensor technologies that will allow system operators and utilities to anticipate, identify, and respond to issues on the grid more quickly;
4. Advancing grid-scale storage technology megawatt-scale storage capable of supporting regulation, ramping and energy management for bulk and distribution power systems; and
5. Helping Puerto Rico and the U.S. Virgin Islands in their efforts to improve the long-term recovery and resilience of their electric infrastructure.

We also recently announced $40 million in funding for the Grid Modernization Initiative, to develop technology innovations to modernize the nation's grid and ensure that it remains resilient, reliable and secure.

Renewables are an essential and growing part of our nation's energy portfolio. They increase our energy diversity and grid resiliency. That's why renewables, along with energy storage and energy efficiency, are critical elements of our overall energy and economic strategy.

The Office of Energy Efficiency and Renewable Energy is also making advances in a number of critical areas at the grid edge, including energy storage, the integration of distributed energy resources, and behind-the-meter systems.

Science Innovation:

Innovation begins with discovery. New energy technologies have their root in basic science. A strong, continued effort in basic science is essential to fuel technology development and keep the engine of innovation running. America's leadership in basic science remains a cornerstone of our security and prosperity.

Through the Office of Science, the Department of Energy is the largest federal sponsor of research in the physical sciences. The DOE Office of Science also is the lead federal agency for basic energy research.

In recent years, the DOE Office of Science has sought to accelerate energy innovation by developing new modalities for sponsoring research, which have resulted in successful programs such as the DOE Energy Frontier Research Centers, the DOE Energy Innovation Hubs, and the DOE Bioenergy Research Centers.

The key to the approach is assembling as a virtual center a multidisciplinary team of researchers from multiple institutions dedicated to making rapid progress in a particular area—and providing proactive oversight of the effort to ensure success. The goal of this team-building is to create a whole that is greater than the sum of its parts.

In addition, these effort are explicitly designed to bridge the usual gap between science and technology by being ever alert to discoveries in basic science that are ripe for technology development and commercialization—and by facilitating the latter through patent applications. As a result, in addition to producing multiple discoveries and breakthroughs in basic science, these programs have generated substantial intellectual property.

In all, these efforts have been enormously productive, producing thousands of peer reviewed publications as well hundreds of inventions at various stages of the patent process.

A second major contribution of DOE's Office of Science is the array of major scientific user facilities at the DOE National Laboratories, which forms part of the backbone of the nation's scientific infrastructure.

DOE supercomputers have recently dominated the headlines. High performance computing has become an enormous powerful tool of both scientific discovery and industrial innovation. The Department of Energy leads the world in high performance computing for science and industry.

Today the U.S. owns five of the top ten supercomputers in in the world, include the #1 and #2 systems, and all five of those U.S. machines are at the DOE National Laboratories.

In addition to the supercomputers, there are the five x-ray light sources—the Linac Coherent Light Source and Stanford Synchrotron Radiation Light Source at SLAC National Accelerator Laboratory; the Advanced Light Source at Lawrence Berkeley National Laboratory; the Advanced Photon Source at Argonne National Laboratory; and National Synchrotron Light Source II at Brookhaven National Laboratory. These have become indispensable instruments for materials science and chemistry as well as biology, medicine, and pharmaceutical discovery.

They, too, are a major source of innovation, as are our neutron scattering facilities and our Nanoscale Science Research Centers.

We are laying the groundwork for a new bio-economy in which a range of environmentally friendly fuels and other products will be produced using engineered microbes and renewable plant feedstocks. A key to that effort is the DOE Joint Genome Institute at LBNL, the world's largest genomic sequencing center for microbes and plants related to energy.

It may be recalled the original idea and impetus for the Human Genome Project came from the Department of Energy, and we continue to be a leader in advancing the science of genomics.

Let me discuss one of these Science Innovations in more detail. Quantum technologies to use the basic theories of quantum mechanics for practical information technology solutions has the real chance of transforming the world, and the National Labs are a key part of U.S. current leadership in this area.

When I testified to this Committee this past September, I noted that Quantum Information Science (QIS) will not only open new vistas for science and technology development, it will also open new commercial markets. There are three areas of applications for QIS: computing, networking, and sensing. Each of these areas can have major jumps in performance as a result of quantum technologies.

The Office of Science has had a significant role in many aspects of QIS research and development. This includes work in basic quantum science, including materials synthesis and processing, instrumentation for quantum control, and theory and modeling of quantum entanglement. It also includes work on quantum devices and systems including qubit technologies, quantum sensors and detectors, novel architectures for quantum computing technologies, software implementation and reliability and quantum networks.

On the last point, I would note that Argonne and Fermilab, along with Caltech, the University of Chicago and the University of Illinois at Urbana-Champaign, are deeply engaged in quantum networking research and development in Chicago. A number of projects are underway there, including a DOE-supported effort to create the Quantum Link, the world's first entangled quantum network, between Argonne and Fermilab."

That network will ultimately teleport information across the 30-mile distance between the two labs, and is expected to be among the longest in the world to send secure information using quantum physics. It offers a completely new way to send information and will be a testbed for developing the science and technology for new quantum possibilities.

This past September, we also announced $218 million in funding for 85 research awards in Quantum Information Science. Scientists at 28 institutions of higher learning and nine DOE National Laboratories developed hardware and software for a new generation of quantum computers, which will synthesize and characterize new materials with special quantum properties and probe how quantum computing and information processing can provide insights into dark matter and black holes.

Finally, I'd also like to acknowledge the National Quantum Initiative Act that the Congress passed and the President signed into law this past December. Through that measure, we'll work with our partners across the federal government to further the frontiers of QIS research and technology and scientific development. We are grateful for your confidence and recognize what it means, in innovation as well as in staying ahead of our competitors overseas.

Innovation Commercialization Efforts:

We are also committed to developing and promulgating policies that support innovation and commercialization -- policies that combine the expertise and capabilities of the National Laboratories with the energy and ideas of the private sector in order to foster commercialization and speed the movement of products from the bench to the marketplace.

For example, we've taken a number of approaches to increasing the impact of CRADAs, Cooperative Research and Development Agreements and SPPs, Strategic Partnership Projects.

This past November, we announced the approval of the Laboratory Agreement Processing Reform initiative, which is designed to streamline the ability of contractors at our National Labs to enter into certain lab partnering agreements within a DOE-approved portfolio of routine work. We anticipate that this will significantly reduce the processing time for agreements, enabling the National Laboratories to concentrate on more complex, potentially higher-impact transactions.

At the same time, we also announced a Liability Reform initiative, which provides more flexibility for the Labs to address indemnity requirements. Indemnity requirements are a common barrier to engagement with the private sector, so we anticipate that this Liability reform will increase the ability of potential partners to work with the National Laboratories by tailoring associated risk to specific circumstances.

Building on a pilot launched under the previous Administration, in late 2017, we made permanent Agreements for Commercializing Technology (ACT), a tool that allows the National Laboratories to be more flexible in working with industry on research and technology projects. We've also expanded the use of ACTs by authorizing a new pilot program called FedACT. This program extends the benefits of ACT to those who wish to partner with DOE's National Labs on federally-funded projects.

DOE is leading the Administration's Lab-To-Market CAP Goal in the President's Management Agenda as co-chair of the interagency committee, by focusing on reducing regulatory and administrative burdens through greater clarity and consistency; increasing private sector engagement through agile, streamlined partnering and licensing agreements based on best practices; and building a more entrepreneurial R&D workforce by leveraging entrepreneurship programs that represent best practices and better managing conflicts of interest.

The Administration, led by the Department of Commerce's National Institute of Standards and Technology, recently released a draft Green Paper detailing 15 key actions to modernize the U.S. system of technology transfer and innovation to meet America's economic and national security needs for the 21st Century. DOE is working closely with NIST and other partners on this important effort.

In addition, we have designated the Director of the Office of Technology Transitions as the Department's Chief Commercialization Officer. Led by the Chief Commercialization Officer, the office will have elevated status and visibility in driving and promoting DOE technology, showcasing our capabilities and facilities, and increasing the impact of our investments. They will continue to oversee OTT's Partnerships and Investment outreach team, the Technology Commercialization Fund, the Technology-to-Market program, and the coordination of technology transfer activities and best practices across the DOE complex.

Just last month, DOE established a Research and Technology Investment Committee (RTIC) following requirements of the DOE Research and Innovation Act that became law last fall. The purpose of the RTIC is to convene key elements of the Department that support research and development activities to share and coordinate their strategic research priorities, identify potential cross-cutting opportunities in both basic and applied science and technology, and ensure key upcoming decisions are effectively leveraged.

Additionally, DOE has kicked off a new series of Summits called Innovation XLab, the most recent of which was on Grid Modernization, as I mentioned earlier. The XLab Summits are designed to increase the engagement of the National Labs with the private sector on high-impact, and potentially transformative, innovations and technologies.

Innovation XLab Summits facilitate a two-way exchange of information and ideas between industry, universities, investors and customers with innovators and experts at DOE and our National Labs. We both highlight research from the laboratories that is approaching commercial application and, just as importantly, hear from industry about its current and emerging technical challenges, risk appetite, and investment criteria.

In this way, DOE incorporates "market pull" as an important input into our R&D portfolio planning. This is already leading to promising connections to ensure our economic and energy dominance. Our first XLab Summit highlighted energy storage technology, and our second addressed grid planning, cyber and behind-the-meter technology. We will be hosting future events on advanced manufacturing, genomics, and other topics.

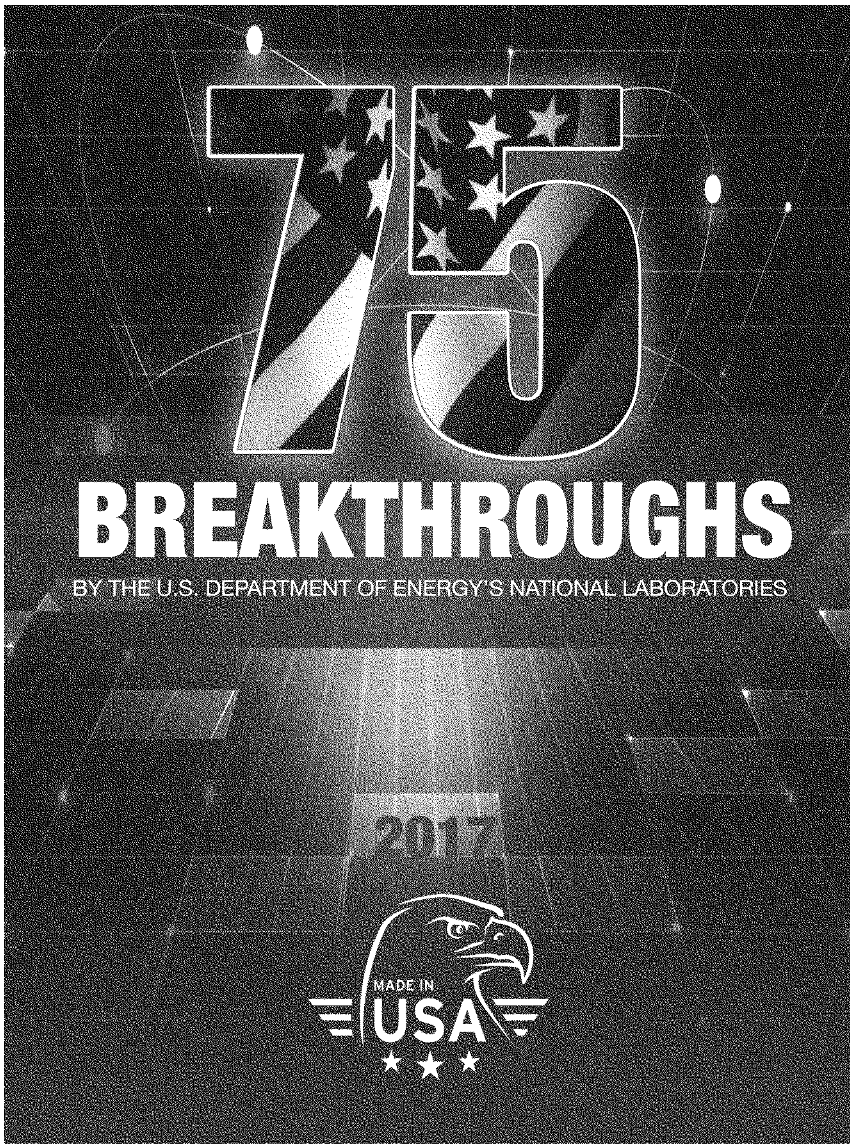
OTT also recently launched the Lab Partnering Service, or LPS. The LPS is an online, single-access platform for investors, innovators and institutions, enabling them to locate and obtain information from and easily contact our 17 National Labs regarding research, capabilities and intellectual property. It represents a significant step in reducing barriers that often limit investors from partnering with our Labs, in consolidating information and increasing access, and in encouraging industry and academia to fully use our world-class resources.

These activities represent only a small portion of our efforts in innovation at the Department of Energy. And this New Year, this new Congress offers new duties, new possibilities, and new opportunities.

We are determined to make the most of them.

As our predecessors have shown the way, we are determined to lead the Department of Energy in making an impact in science and security, in innovation and commercialization. Above all, we are committed to our mission, and to renewed service to our nation.

Thank you, and I look forward to answering your questions.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BROOKHAVEN NATIONAL LABORATORY

Fermilab

INL Idaho National Laboratory

Jefferson Lab Thomas Jefferson National Accelerator Facility

Berkeley Lab Lawrence Berkeley National Laboratory

Lawrence Livermore National Laboratory

Los Alamos NATIONAL LABORATORY

NATIONAL ENERGY TECHNOLOGY LABORATORY

NREL NATIONAL RENEWABLE ENERGY LABORATORY

OAK RIDGE National Laboratory

Pacific Northwest NATIONAL LABORATORY

PPPL PRINCETON PLASMA PHYSICS LABORATORY

Sandia National Laboratories

SLAC NATIONAL ACCELERATOR LABORATORY

SRNL

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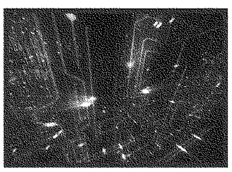
AMERICA'S NATIONAL LABORATORIES . . .

have been changing and improving the lives of millions of people for more than 75 years. Born at a time when the world faced a dire threat, the laboratories came together to advance science, safeguard the nation and protect our freedoms for generations to come. This network of Department of Energy Laboratories has grown into 17 facilities, working together as engines of prosperity and invention. As this list of breakthroughs attests, Laboratory discoveries have spawned industries, saved lives, generated new products, fired the imagination and helped to reveal the secrets of the universe. Rooted in the need to serve the public good and support the global community, the National Laboratories have put an American stamp on the last century of science. With equal ingenuity and tenacity, they are now engaged in innovating the future.

At America's National Laboratories, we've. . .

Advanced supercomputing

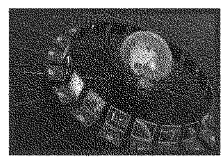


The National Labs operate some of the most significant high performance computing resources available, including 32 of the 500 fastest supercomputers in the world. These systems, working at quadrillions of operations per second, model and simulate complex, dynamic systems – such as the nuclear deterrent – that would be too expensive, impractical or impossible to physically demonstrate. Supercomputers are changing the way scientists explore the evolution of our universe, climate change, biological systems, weather forecasting and even renewable energy.

Decoded DNA

In 1990, the National Labs joined with the National Institutes of Health and other laboratories to kick off the Human Genome Project, an international collaboration to identify and map all of the genes of the human genome.

Brought the web to the United States

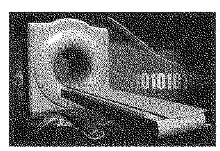


National Lab scientists, seeking to share particle physics information, were first to install a web server in North America, kick-starting the development of the worldwide web as we know it.

Put eyes in the sky

Vela satellites, first launched in 1963 to detect potential nuclear detonations, transformed the nascent U.S. space program. The satellites featured optical sensors and data processing, logic and power subsystems designed and created by National Labs.

Revolutionized medical diagnostics and treatment



Researchers at the National Labs helped to develop the field of nuclear medicine, producing radioisotopes to diagnose and treat disease, designing imaging technology to detect cancer and developing software to target tumors while sparing healthy tissue.

Powered NASA spacecraft

The National Labs built the enclosure for the radioisotope thermoelectric generators that fuel crafts such as Cassini and have begun producing plutonium-238 for future NASA missions.

Harnessed the power of the atom

National Lab scientists and engineers have led the world in developing safe, efficient and emissions-free nuclear power. Starting with the first nuclear reactor to generate electricity, National Labs have been the innovation engine behind the peaceful use of nuclear energy. Today's labs are supporting the next generation of nuclear power that will be available for the nation and world.

Brought safe water to millions

Removing arsenic from drinking water is a global priority. A long-lasting particle engineered at a National Lab can now do exactly that, making contaminated water safe to drink. Another technology developed at a National Lab uses ultraviolet light to kill water-borne bacteria that cause dysentery, thus reducing child mortality in the developing world.

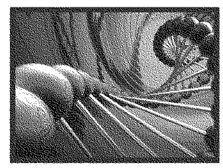
Filled the Protein Data Bank

National Lab X-ray facilities have contributed a large portion of more than 100,000 protein structures in the Protein Data Bank. A protein's structure reveals how it functions, helping scientists understand how living things work and develop treatments for disease. Almost all new medications that hit the market start with these data bank structures.

Invented new materials

National Labs provide the theory, tools and techniques that offer industry revolutionary materials such as strong, lighter-weight metals and alloys that save fuel and maintenance costs and enable cleaner, more efficient engines.

Found life's mystery messenger

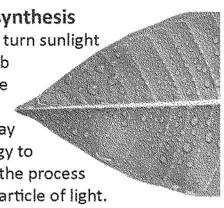


National Lab scientists discovered how genetic instructions are carried to the cell's protein manufacturing center, where all of life's processes begin. Subsequent light source research on the genetic courier, called messenger RNA, has revealed how the information is transcribed and how mistakes can cause cancer and birth defects.

Mapped the universe — and the dark side of the moon

Credit for producing 3D maps of the sky — and 400 million celestial objects — goes to National Lab scientists, who also developed a camera that mapped the entire surface of the moon.

Shed light on photosynthesis



Ever wonder how plants turn sunlight into energy? National Lab scientists determined the path of carbon through photosynthesis, and today use X-ray laser technology to reveal how each step in the process is triggered by a single particle of light. This work helps scientists explore new ways to get sustainable energy from the sun.

Solved cultural mysteries

The works of ancient mathematician Archimedes — written over by medieval monks and lost for millennia — were revealed to modern eyes thanks to the X-ray vision and light-source technology at National

Labs. These studies also have revealed secrets of masterpiece paintings, ancient Greek vases and other priceless cultural artifacts.

Revolutionized accelerators

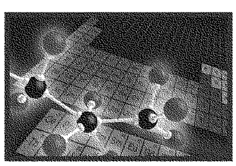
A National Lab built and operated the first large-scale accelerator based on superconducting radio frequency technology. This more efficient technology now powers research machines for exploring the heart of matter, examining the properties of materials and providing unique information about the building blocks of life.

Revealed the secrets of matter

Protons and neutrons were once thought to be indivisible. National Lab scientists discovered that protons and neutrons were made of even smaller parts, called quarks. Over time, experimenters identified six kinds of quarks, three types of neutrinos and the Higgs particle, changing our view of how the material world works.

Confirmed the Big Bang and discovered dark energy

National Lab detectors aboard a NASA satellite revealed the birth of galaxies in the echoes of the Big Bang. Dark energy — the mysterious something that makes up three-quarters of the universe and causes it to expand at an accelerating rate — also was discovered by National Lab cosmologists.



Discovered 22 elements

The periodic table would be smaller without the National Labs. To date the National Labs have discovered: technetium, promethium, astatine, neptunium, plutonium, americium, curium, berkelium, californium, einsteinium, fermium, mendelevium, nobelium, lawrencium, rutherfordium, dubnium, seaborgium, flerovium, moscovium, livermorium, tennessine and oganesson.

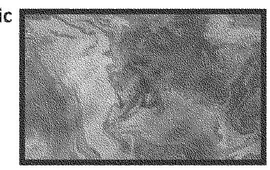
Made refrigerators cool

Next-generation refrigerators will likely put the freeze on harmful chemical coolants in favor of an environmentally friendly alloy, thanks to National Lab scientists.

Got the lead out

Removing hazardous lead-based solders from the environment is a reality thanks to a lead-free alloy of tin-silver-copper developed at a National Lab. The lead-free solder has been licensed by more than 60 companies worldwide.

Invented a magic sponge to clean up oil spills



National Lab scientists used a nano technique to invent a new sponge that can absorb 90 times its own weight in oil from water. It can be wrung out to collect the oil and reused hundreds of times — and it can collect oil that has sunk below the surface, something previous technology couldn't do.

Added the punch to additive manufacturing

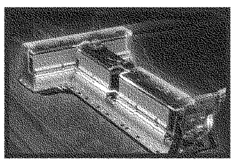
High-pressure gas atomization processing pioneered at a National Lab made possible the production of titanium and other metal-alloy powders used in additive manufacturing and powder metallurgy.

Created inexpensive catalysts

Low-cost catalysts are key to efficient biomass refining. National Lab scientists created catalysts that are inexpensive and stable for biomass conversion.

Created high-tech coatings to reduce friction

National Lab scientists created ways to reduce wear and tear in machines from table fans to car engines all the way up to giant wind turbines, such as a diamond-like film that rebuilds itself as soon as it begins to break down — so that engines last longer and need fewer oil additives.



Put the jolt in the Volt

Chevy's Volt would not be able to cruise on battery power were it not for the advanced cathode technology that emerged from a National Lab. The same technology is sparking a revival of America's battery manufacturing industry.

Cemented a new material

National Lab scientists have developed a novel and versatile material that blends properties of ceramic and concrete to form a non-porous product that can do everything from seal oil wells to insulate walls with extra fire protection. It even sets in cold weather.

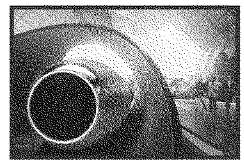
Pioneered efficient power lines

New kinds of power lines made from superconductors can carry electric current with no energy loss. Now deployed by National Lab scientists, these prototypes could usher in a new era of ultra-efficient power transmission.

Made early universe quark soup

National Lab scientists used a particle collider to recreate the primordial soup of subatomic building blocks that last existed shortly after the Big Bang. The research is expanding scientists' understanding of matter at extreme temperatures and densities.

Levitated trains with magnets



Say goodbye to traffic jams. National Lab scientists developed a technology that uses the attractive and repulsive forces of magnets to levitate and propel trains. Maglev trains now ferry commuters in Japan and China and will be operational in other countries soon.

Developed efficient burners

National Lab researchers developed cleaner-combusting oil burners, saving consumers more than $25 billion in fuel costs and keeping more than 160 megatons of carbon dioxide out of Earth's atmosphere.

Improved automotive steel

A company with National Lab roots is pioneering a metal that weighs significantly less than regular steel, retains steel's strength and malleability and can be fabricated without major modifications to the automotive manufacturing infrastructure.

Looked inside weapons

National Lab researchers created a device that could identify the contents of suspicious chemical and explosive munitions and containers, while minimizing risk to the people involved. The technology, which quickly identifies the chemical makeup of weapons, has been used to verify treaties around the world.

Pioneered nuclear safety modeling

National Lab scientists began developing the Reactor Excursion and Leak Analysis Program

(RELAP) to model nuclear reactor coolant and core behavior. Today, RELAP is used throughout the world and has been licensed for both nuclear and non-nuclear applications, including modeling of jet aircraft engines and fossil-fuel power plant components.

Identified good and bad cholesterol

The battle against heart disease received a boost in the 1960s when National Lab research unveiled the good and bad sides of cholesterol. Today, diagnostic tests that detect both types of cholesterol save lives.

Unmasked a dinosaur killer

Natural history's greatest whodunit was solved in 1980 when a team of National Lab scientists pinned the dinosaurs' abrupt extinction on an asteroid collision with Earth. Case closed.

Pitted cool roofs against carbon dioxide

National Lab researchers and policy experts led the way in analyzing and implementing cool roofing materials, which reflect sunlight, lower surface temperature and slash cooling costs.

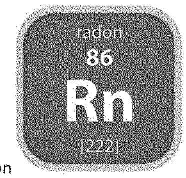
Squeezed fuel from microbes

In a milestone that brings advanced biofuels one step closer to America's gas tanks, National Lab scientists helped develop a microbe that can produce fuel directly from biomass.

Tamed hydrogen with nanoparticles

To replace gasoline, hydrogen must be safely stored and easy to use, which has proven elusive. National Lab researchers have now designed a new pliable material using nanoparticles that can rapidly absorb and release hydrogen without ill effects, a major step in making fuel-cell powered cars a commercial reality.

Exposed the risk



You can sleep easier thanks to National Lab research that quantified the health risk posed by radon gas in parts of the country. Subsequent EPA standards, coupled with radon detection and mitigation measures pioneered by a National Lab research team, prevent the naturally occurring gas from seeping into basements, saving thousands of lives every year.

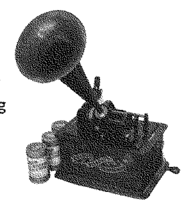
Created a pocket-sized DNA sampler

A tool that identifies the microbes in air, water and soil samples is fast becoming a workhorse in public health, medical and environmental cleanup projects. Developed by National Lab scientists, the credit-card-sized device pinpoints diseases that kill coral reefs and catalogs airborne bacteria over U.S. cities. It also was used to quickly categorize the oil-eating bacteria in the plumes of the Deepwater Horizon spill.

Fabricated the smallest machines

The world's smallest synthetic motors — as well as radios, scales and switches that are 100,000 times finer than a human hair — were engineered at a National Lab. These and other forays into nanotechnology could lead to life-saving pharmaceuticals and more powerful computers.

Preserved the sounds of yesteryear



National Lab scientists engineered a high-tech way to digitally reconstruct aging sound recordings that are too fragile to play, such as Edison wax cylinders from the late 1800s. Archivists estimate that many of the millions of recordings in the world's sound archives, including the U.S. Library of Congress, could benefit from the technology.

Exposed explosives

A credit-card sized detector developed by National Lab scientists can screen for more than 30 kinds of explosives in just minutes. The detector, called ELITE, requires no power and is widely used by the military, law enforcement and security personnel.

Toughened airplanes

A National Lab and industry technique for strengthening metal by bombarding it with laser pulses has saved the aircraft industry hundreds of millions of dollars in engine and aircraft maintenance expenses.

Simulated reality

Trains, planes and automobiles — and thousands of other objects — are safer, stronger and better-designed thanks to computer simulation software, DYNA 3D, developed by National Lab researchers.

Detected the neutrino

Starting with the Nobel-Prize winning discovery of the neutrino in 1956 by Fred Reines and Clyde Cowan Jr., National Lab researchers have made numerous contributions to neutrino physics and astrophysics.

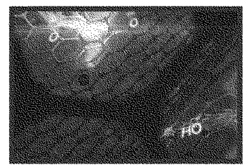
Discovered gamma ray bursts

Sensors developed at the National Labs and placed aboard Vela satellites were used in the discovery of gamma-ray bursts (GRBs) in 1973. GRBs are extremely energetic explosions from distant galaxies. Scientists believe that most of these bursts consist of a narrow beam of intense radiation released when a rapidly rotating, high-mass star collapses to form a neutron star, a quark star or a black hole.

Created the first 100-Tesla magnetic field

National Lab scientists achieved a 100.75-Tesla magnetic pulse in March 2012, setting a world record. The pulse was nearly 2 million times more powerful than Earth's magnetic field. The 100-Tesla multi-shot magnet can be used over and over again without being destroyed by the force of the field it creates, and produces the most powerful non-destructive magnetic field in the world.

Froze smoke for hot uses



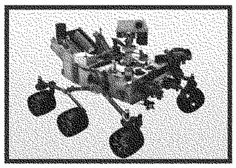
National Labs researchers perfected aerogels, known as frozen smoke. They are one of the lightest solids ever made and have the highest heat resistance of any material tested. They also are fireproof and extraordinarily strong — able to support more than a thousand times their own weight. As a result of their heat resistance, aerogels are outstanding candidates for insulation in buildings, vehicles, filters and appliances.

Invented the cell sorter

During the 1960s, a National Lab physicist invented a "cell sorter" — a novel device that works much like an ink jet printer, guiding a tiny flow of cell-containing droplets so cells of interest can be deflected for counting and study. Cell sorters are a vital tool for studying the biochemistry behind many diseases, including cancer and AIDS.

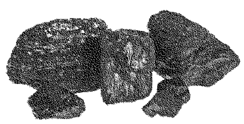
Ushered a domestic energy renaissance

National Lab research jump-started the shale gas revolution by pointing the way to key technologies and methodologies for cost efficient extraction. An estimated $220 million in research and development expenditures on unconventional gas R&D from 1976 to 1992 have resulted in an estimated $100 billion in annual economic activity from shale gas production alone.



Enabled space exploration

National Labs invented Laser-Induced Breakdown Spectroscopy (LIBS), the backbone of the device that allowed the Curiosity Rover to analyze material from Mars. Lab researchers also found the right combination of materials to make high-efficiency solar cells for spacecraft.



Sharply curtailed power plant air emissions

National Lab scientists introduced some 20 innovative technologies — such as low nitrogen oxide (NOx) burners, flue gas desulfurization (scrubbers) and fluidized bed combustion — through the Clean Coal Technology Development Program that have deeply penetrated the marketplace, substantially controlled harmful power plant emissions and benefited energy production and air quality.

Made wind power mainstream

Increasing wind turbine efficiency with high efficiency airfoils has reduced the cost of wind power by more than 80 percent over the last 30 years. Now deployed in wind farms nationwide, these turbines owe their existence to National Lab research.

Engineered smart windows

National Lab scientists have created highly insulated windows that change color to modulate interior temperatures and lighting. If broadly installed, they could save about 5 percent of the nation's total energy budget.

Delivered troops safely

National Lab researchers have developed computer models that effectively manage the complex logistical tasks of deploying troops and equipment to distant destinations.

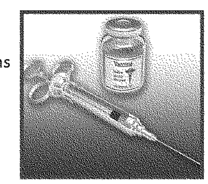
Channeled chips and hips

Integrated circuits and artificial hips owe their success to a National Lab discovery that revealed how to change a material by injecting it with charged atoms, called ions. Ion channeling is now standard practice in industry and science.

Made 3D printing bigger and better

A large-scale additive manufacturing platform developed by a National Lab and an industry partner printed 3D components 10 times larger and 200 times faster than previous processes. So far, the system has produced a 3D-printed sports car, SUV, house, excavator and aviation components.

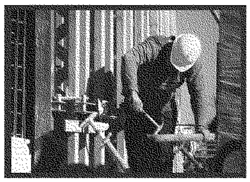
Purified vaccines



National Lab researchers adapted nuclear separations technology to develop a zonal centrifuge used to purify vaccines, which reduces or eliminates unwanted side effects. Commercial centrifuges based on the invention produce vaccines for millions of people.

Built a better building

A National Lab has built one of the world's most energy efficient office buildings. The facility, operating as a living laboratory at a lab site, uses 50



percent less energy than required by commercial codes and only consumes energy produced by renewable power on or near the building.

Improved airport security
Weapons, explosives, plastic devices and other concealed tools of terrorists are easier to detect thanks to technology developed at a National Lab and now installed in airports worldwide.

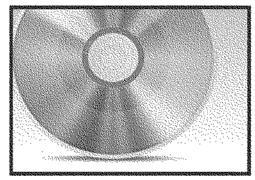
Improved grid resiliency
A National Lab created an advanced battery that can store large amounts of energy from intermittent renewable sources — such as wind and solar — onto the power grid, while also smoothing over temporary disruptions to the grid. Several companies have licensed the technology and offer it as a commercial product.

Solved a diesel dilemma
A National Lab insight into how catalysts behave paved the way for a new, "lean-burn" diesel engine that met emissions standards and improved fuel efficiency by 25 percent over conventional engines.

Harvested energy from air
A miniature device — commercialized by private industry after a National Lab breakthrough — generates enough power from small temperature changes to power wireless sensors or radio frequency transmitters at remote sites, such as dams, bridges and pipelines.

Gone grid friendly
Regulating the energy use of household appliances — especially at peak times — could slash energy demand and avoid blackouts. A National Lab appliance-control device senses grid stress and responds instantly to turn off machines and reduce end-use demand, balancing the system so that the power stays on.

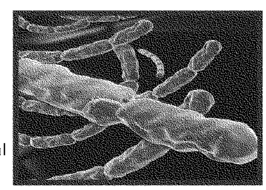
Put the digital in DVDs



The optical digital recording technology behind music, video and data storage originated at a National Lab nearly 40 years ago.

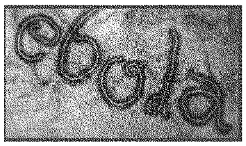
Locked nuclear waste in glass
Disposal of U.S. Cold War waste is safer thanks to National Lab scientists who developed and deployed a process to lock it into glass to keep it from leaching into the environment.

Cleaned up anthrax



Scientists at a National Lab developed a non-toxic foam that neutralizes chemical and biological agents. This foam was used to clean up congressional office buildings and mail rooms exposed to anthrax in 2001.

Removed radiation from Fukushima seawater
After a tsunami damaged the Fukushima Daiichi nuclear power plant in 2011, massive amounts of seawater cooled the reactor. A molecular sieve engineered by National Lab scientists was used to extract radioactive cesium from tens of millions of gallons of seawater.



Sped up Ebola detection

In 2014, researchers from a National Lab modeled the Liberian lood sample transport system and made ecommendations to diagnose patients quicker. This ninimized the amount of time people were waiting ogether, reducing the spread of Ebola.

revented unauthorized use of a nuclear veapon

n 1960, National Lab scientists invented coded lectromechanical locks for all U.S. nuclear weapons. he switch blocks the arming signal until it receives he proper presidential authorization code.

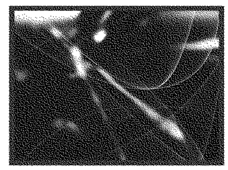
aunched the LED lighting revolution

n the 1990s, scientists at a National Lab saw the eed for energy-efficient solid-state lighting and vorked with industry to develop white LEDs. Today, vhite LEDs are about 30 percent efficient, with the otential to reach 70 percent to 80 percent efficiency. luorescent lighting is about 20 percent efficient and ncandescent bulbs are 5 percent.

Aastered the art of artificial photosynthesis

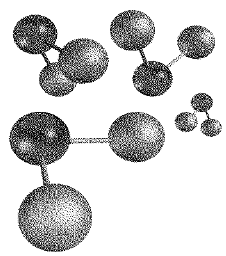
lational Lab scientists engineered and synthesized nulti-layer semiconductor structures in devices hat directly convert sunlight to chemical energy in ydrogen by splitting water at efficiencies greater than 15 percent. This direct conversion of sunlight to fuels paves the way for use of solar energy in applications beyond the electrical grid.

Advanced fusion technology

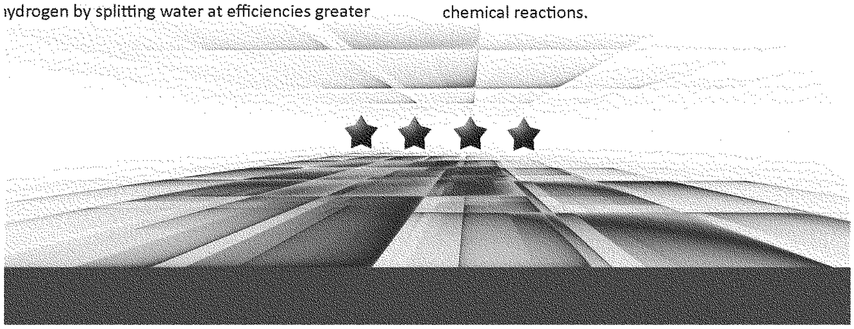


From the first fusion test reactor to briefly produce power at the megawatt scale, and the world's largest and most energetic laser creating extreme conditions mimicking the Big Bang, the interiors of planets and stars and thermonuclear weapons, to the international experiment to generate industrial levels of fusion energy from burning plasmas, fusion science and applications are advancing because of the National Labs.

Made the first molecular movie



National Lab scientists have used ultrafast X-rays to capture the first molecular movies in quadrillionths-of-a-second frames. These movies detail the intricate structural dances of molecules as they undergo chemical reactions.

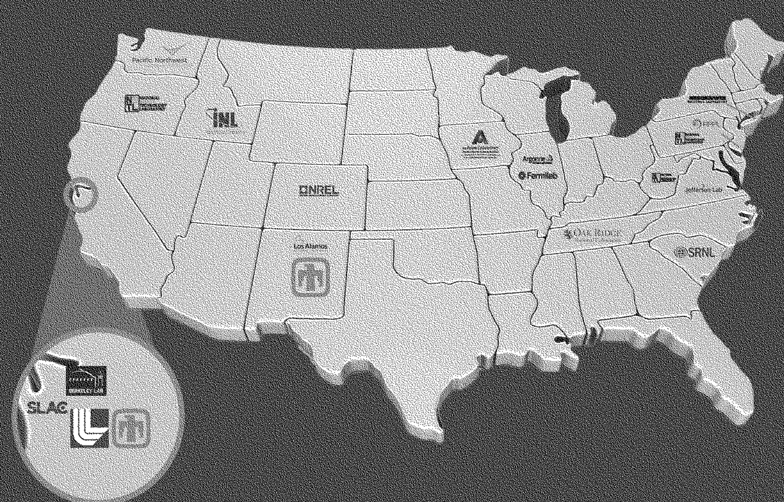


The National Laboratory System

Protecting America Through Science and Technology

U.S. DEPARTMENT OF ENERGY

For more than 75 years, the Department of Energy's national laboratories have solved important problems in science, energy and national security. This expertise keeps our nation at the forefront of science and technology in a rapidly changing world. Partnering with industry and academia, the laboratories also drive innovation to advance economic competitiveness and ensure our nation's future prosperity.



Ames Laboratory
Ames, Iowa

Argonne National Laboratory
Argonne, Illinois

Brookhaven National Laboratory
Upton, New York

Fermi National Accelerator Laboratory
Batavia, Illinois

Idaho National Laboratory
Arco, Idaho

Lawrence Berkeley National Laboratory
Berkeley, California

Lawrence Livermore National Laboratory
Livermore, California

Los Alamos National Laboratory
Los Alamos, New Mexico

National Energy Technology Laboratory
Albany, Oregon; Morgantown, West Virginia; and Pittsburgh, Pennsylvania

National Renewable Energy Laboratory
Golden, Colorado

Oak Ridge National Laboratory
Oak Ridge, Tennessee

Pacific Northwest National Laboratory
Richland, Washington

Princeton Plasma Physics Laboratory
Princeton, New Jersey

Sandia National Laboratory
Albuquerque, New Mexico

Savannah National Laboratory
Aiken, South Carolina

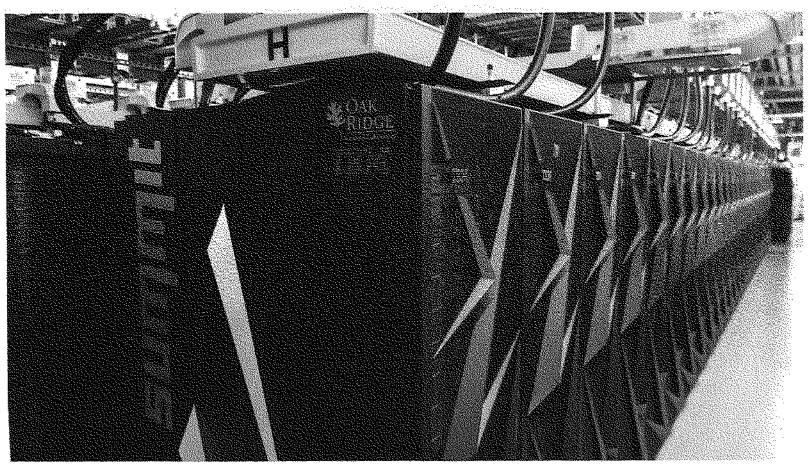
SLAC National Accelerator Laboratory
Menlo Park, California

Thomas Jefferson National Accelerator Facility
Newport News, Virginia

Department of Energy

American Scientific Leadership in the 21st Century

JANUARY 29, 2019



Oak Ridge National Laboratory's Summit, the world's fastest supercomputer, is just one example of the Energy Department's scientitfic leadership in America.

The prosperity, security, and national competitiveness of the United States depend on science and innovation. Due to the inquisitiveness of the American mind, our entrepreneurial spirit as a people, and government's support for basic and early stage research in partnership with universities and private sector research, America is unsurpassed in scientific discovery and innovation. The Administration and Congress, through their support of the Office of Science and the entire DOE national laboratory complex, have made it clear that America is committed to remaining a wellspring of scientific understanding, technological sophistication, and engineering skill not only for today, but throughout the 21st Century.

The White House Office of Science and Technology Policy (OSTP) articulated the important role that the federal government plays in scientific research, without supplanting the roles of the private sector and universities:

> *"Federal R&D dollars focused primarily on basic and early-stage applied research, paired with targeted deregulation, and investment in science, technology, engineering, and mathematics (STEM) education and workforce development, will strengthen the Nation's innovation base and position the United States for unparalleled job growth, continued prosperity, and national security."*

DOE's Office of Science (SC) plays a vital role in the pursuit of this national agenda. Tackling the most daunting Science and Technology (S&T) challenges, SC sponsors groundbreaking research and provides the academic and commercial sectors with uniquely powerful tools of discovery and analysis. In FY2019, SC will continue to invest in a wide variety of pioneering research, including new emphases on several innovative fields with great potential to enhance human wellbeing. Through pioneering research, coordinated with other federal research and development investments, SC will contribute to America's S&T pre-eminence.

The Office of Science Plays a Vital Role in American Scientific Achievement

In the Information Age, SC must ensure that the United States occupies the commanding heights of scientific knowledge and the means of scientific discovery. The Office of Science (SC) and the whole national laboratory complex support a diverse portfolio of research that advances the science needed for revolutionary energy breakthroughs, seek to unravel nature's deepest mysteries, and provide the Nation's researchers with the most advanced large-scale tools of modern science.

The Office of Science manages this research portfolio through six core program offices: Advanced Scientific Computing Research, Basic Energy Sciences, Biological and Environmental Research, Fusion Energy Sciences, High Energy Physics, and Nuclear Physics.

In addition, the Office of Science manages and supports additional programs and activities, including the Workforce Development for Teachers and Scientists program, the DOE Small Business Innovation Research / Small Business Technology Transfer programs, and the Office of Project Assessment.

National Laboratories

The Office of Science oversees management of 10 of the 17 DOE national laboratories and supports research at all of them. These world-leading facilities, which employ more than 58,000 scientists, technicians, and other staff, perform pioneering basic research across a wide range of scientific fields. The laboratories constitute a pre-eminent federal research enterprise, providing the Nation with strategic scientific and technological capabilities. The national labs:

- **Execute long-term government scientific and technological missions, often with complex security, safety, project management, or other operational aspects;**
- **Develop unique, often multi-disciplinary, scientific capabilities beyond the scope of academic and industrial institutions, to benefit the Nation's researchers and national strategic priorities; and**
- **Develop and sustain critical scientific and technical capabilities to which the government enjoys assured access and from which it obtains ongoing innovation.**

Our national laboratories are the envy of the world, and the Office of Science is proud that it has been entrusted with the stewardship of these "crown jewels" of the

American innovation ecosystem.

Thresholds of Transformation

The importance of the Office of Science is underscored by the breadth of its scope and its role in many high-impact areas of innovation. Since taking office, the Department's leadership has highlighted the exciting status of six areas of technology with potentially transformative benefits to humankind: advanced and sustainable energy, genomics, machine learning and artificial intelligence, advanced mobility, space exploration, and quantum information science (QIS). Major breakthroughs are nearly within our grasp in these areas. DOE's national laboratories are contributing to progress in all six, with Office of Science financial assistance and Office of Science user facilities making invaluable contributions.

Curiosity and Usefulness

The origins of the Office of Science underscore its potentially dramatic impact on American life. The Office of Science traces its origins to scientists working for the Manhattan Project in what became the country's first national laboratories. Their investigations of sub-atomic physics and development of accelerators, colliders, and other tools gave rise over time to a host of unforeseen discoveries and technologies, including the field of nuclear medicine and discoveries in genomics and innovative energy technologies. In a similar fashion, even the most esoteric explorations the Office of Science supports today hold the potential to enable great advances in human knowledge and well-being. While pursuing fundamental understanding of the physical world and its phenomena, the scope of Office of Science investigations encompasses both research without readily apparent near-term applications and problem-solving research—in Prof. Donald Stokes's nomenclature, work in both Bohr's quadrant of basic research and in Pasteur's quadrant of use-inspired research.

Planning and Discipline

Office of Science programs have demonstrated the benefits of long-range planning and disciplined project management. Through deep engagement with leading experts and organizations in their respective fields, Office of Science programs have benefited from varied perspectives and helped to foster consensus with respect to the most promising scientific infrastructure and topics for research. The Office of Science's well-formulated plans enabled the prompt commencement of construction projects in response to appropriations, such as upgrades to the light sources at Argonne National Laboratory, Lawrence Berkeley National Laboratory, and SLAC National Accelerator Laboratory and to the neutron source at Oak Ridge National Laboratory, to name a few.* The national labs are well poised to continue delivering major projects on time and under budget, as with the recently-completed upgrade to the Continuous Electron Beam Accelerator Facility at Thomas Jefferson National Accelerator Facility. The Office of Science commissioned Summit, the fastest supercomputer in the world, at Oak Ridge National Laboratory and is already creating three significantly more powerful exascale computing facilities in the national lab complex. Argonne Lab and Fermi National Accelerator Facility, working with the University of Chicago, have formed the Chicago Quantum Exchange and are creating a unique 30-mile network to demonstrate communications through quantum entanglement. In the near future, the Office of Science expects to begin developing the Electron-Ion Collider, a next generation facility to explore the interiors of protons and neutrons. The creation and operation of this unsurpassed portfolio of user facilities are essential to maintaining American S&T leadership.

Lab-to-Market

In accord with the Administration's cross-agency lab-to-market initiative goals, the Office of Science will continue to foster collaboration among national labs, other research institutions, state and local governments, and private enterprises. While Office of Science-sponsored investigations are inherently pre commercial, investigators are encouraged to reflect on potential uses for their discoveries, take appropriate steps to establish intellectual property rights, and entertain wide- ranging dialogues that may transform emerging knowledge into innovative applications.

Global Context

Great scientific discoveries also come from collaborations and reciprocal exchanges that cross national borders. American participation in overseas projects like the Large Hadron Collider in Europe and foreign participation in U.S.-based projects like the Long Baseline Neutrino Facility / Deep Underground Neutrino Experiment are outstanding examples of international cooperation. The Office of Science plans to accelerate the identification and execution of opportunities for fruitful cooperation and knowledge sharing with counterparts and investigators from around the world. At the same time, the Office of Science will responsibly steward the investment of American taxpayers. In doing so, we expect fairness and reciprocity; while proudly cooperating with foreign partners through authorized channels, the Office of Science will maintain a vigilant guard against illicit and potentially harmful foreign exploitation of its resources. The Department must be attentive to the challenge posed by other nations, not merely through targeted investments in research, but through outright theft of American intellectual property.

FY2019 SC R&D Priorities

In the 2019 fiscal year, we directed the Office of Science to give special emphasis and priority to seven R&D initiatives: (1) machine learning / artificial intelligence (ML / AI); (2) QIS; (3) microelectronics innovation; (4) fusion energy; (5) bioscience; (6) isotopes supply capabilities; and (7) cross cutting enabling technologies for user facilities. Among these topics, artificial intelligence, QIS, and advanced microelectronics were called out for emphasis by OSTP's FY2020 budget priorities memorandum as well.

Machine Learning / Artificial Intelligence

Cutting-edge research in a wide array of topics, from sub-atomic particle experiments to public health investigations, generate enormous volumes of data in which critical clues can be hidden and connections can be difficult to discover. Advances in ML / AI will enable transformative scientific breakthroughs in such fields within and outside the DOE mission space, especially when applied through the Office of Science's leadership computing facilities (LCF). For example, in addition to being the fastest computer in the world, the Summit LCF that DOE commissioned at Oak Ridge National Laboratory earlier this year was designed from the ground up to be the most powerful one for machine learning. With its high-performance computing expertise and its access to enormous data sets, including data from user facilities and from other government agencies, the Office of Science is uniquely positioned to facilitate the development of ML / AI techniques and hardware.

Quantum Information Science

At sub-atomic scales, matter and energy behave in strange ways that offer extraordinary opportunities for unconventional sensing, network communications, and computing. These opportunities include functions that could not be performed by even the most advanced devices using classical mechanics and computing methods at the outer realm of forecasted possibilities. Such devices would potentially provide unprecedented security in communications, scientific and medical diagnostics of unmatched sensitivity, and tools for simulations and calculations beyond the reach of classical computing methods. Recent progress in materials science and technology have made the creation of such systems more feasible than ever before. While other nations have begun significant investments in QIS, the U.S. can maintain leadership in this challenging field—harnessing quantum behaviors into powerful applications—through interagency efforts that exploit the unrivaled facilities and expertise in physics and computing provided by the Office of Science. In doing so, we are confident that important QIS innovations in computing, network communications, and sensing will emerge.

Microelectronics Innovation

The pace of improvement in classical computing performance, density, and energy usage predicted by Moore's Law and Dennard scaling have slowed as existing materials and design paradigms approach physical nanoscale limits. The continuous progress that has been manifested in everything from smaller, more powerful smartphones to faster LCF supercomputers cannot be sustained without innovations in microchip architectures, design procedures, and manufacturing methods. But with groundbreaking R&D in these areas, our Nation can take classical computing beyond Moore's Law and reestablish American leadership in microelectronics. In coordination with other federal agencies, the Office of Science will invest in efforts to discover materials, architectures, and fabrication methods needed to achieve these goals.

Fusion Program Acceleration

The development of fusion power generation holds the key to providing nearly unlimited energy to power the world in a clean a responsible manner. Fusion—the process that powers the Sun—utilizes abundant natural elements and creates no spent- fuel waste. Our mix of governmental, academic, and private enterprise investments in fusion energy research creates unique opportunities for synergistic collaboration and American leadership in this field. Recent substantial increases in appropriations also position the Office of Science to accelerate the pace of development in fusion energy. While we continue to support international collaborations in fusion research, we are working to accelerate U.S.-based leadership in the science through the national labs, U.S. universities, and increased interaction with the world's leading private fusion innovation community.

Bioscience

The Office of Science has a well-established role in genomics and other fields of biological science, including a key role in the Human Genome Project. Fundamental research in genomics and other aspects of bioscience is germane to a variety of DOE missions concerning fuels, energy efficiency, advanced manufacturing, environmental management, and national security. The methods that are developed in working on such DOE mission topics missions also hold great promise for use in other fields, such as development of precision medicines and advanced agriculture. Programs such as Joint Genome Institute will continue to be important Office of Science investments that will pay future dividends across a wide field of technologies.

Isotopes Production

The Office of Science is a vital supplier of radioactive and stable isotopes for research and applications such as medical diagnostics and therapies. For varied isotopes that lack commercial suppliers, DOE fills the gap by stewarding processing facilities in national labs and supporting isotope production at academic and commercial facilities across the country. As the important High Flux Isotope Reactor ages, new isotope production methods are developed, and new isotope-based applications are increasingly identified, the Office of Science is well positioned to revisit its isotope program, including potential investment in new or rejuvenated facilities to meet the nation's needs.

Cross-Cutting Enabling Technologies

The Office of Science already operates some of the largest, most complex, and most powerful scientific infrastructure in the world, including light sources and particle colliders. The next generation of Office of Science user facilities can be even more powerful, if we improve vital hardware components that drive them. Many of these components have cross-cutting applications; powerful magnetics, for example, contribute to particle accelerators and fusion science research both, among other things. In connection with plans for future world-leading user facilities, the Office of Science will be investing in materials research and other explorations to develop next-generation particle accelerators, stronger high-field magnets, and more advanced superconducting radiofrequency cavity technologies.

Dedication to American Leadership

While respectful of fellow explorers and mindful of the sometimes awesome challenges faced at the frontiers of knowledge and engineering skills, the U.S. is committed to its pre-eminence in science and technology. As a nation, we celebrate our collaborations and respectfully recognize our peers, but we must always strive to be unsurpassed in scientific discovery, technology, and innovation. Along with world-class educational systems and research universities and energetic private enterprise, the ongoing investment and performance by the programs of DOE's Office of Science are essential to our national goal of being second to none.

PAUL M. DABBAR

Paul Dabbar is the Under Secretary for Science, serving as the Energy Department's principal advisor on fundamental energy research, energy technologies, and science.

MORE BY THIS AUTHOR

The CHAIRMAN. Thank you. We appreciate that. And rest assured, we too are trying to get these nominees through the process just as quickly as we can. You need to have your full team up and running and particularly in these key areas. So thank you for that, and thank you for your testimony this morning.

Secretary Moniz, it is a pleasure.

STATEMENT OF HON. ERNEST J. MONIZ, FOUNDER AND CEO, ENERGY FUTURES INITIATIVE

Dr. MONIZ. Well thank you, Chairman Murkowski and Ranking Member Manchin and members of the Committee, most of whom are extremely familiar, and I must say I've been testifying before this Committee and Chairman Murkowski for more than two decades. And I thank the Chair and the Ranking Member also for the time yesterday when we could discuss our new report. I've always been happy to work with this Committee in a bipartisan way and look forward to helping any way we can going forward. Also I'd like to recognize Under Secretary Dabbar whose background also in investment banking and I think is a very, very good background for this, this subject.

Much of my career has focused on innovation from initiating the MIT Energy Initiative which had new ways of working with the energy industry, my tenure as Secretary making innovation a cornerstone of our approach to energy—our energy policy and initiatives; now in a new organization, the Energy Futures Initiative, from which we issued yesterday this report, "Advancing the Landscape of Clean Energy Innovation," and this is a report done in collaboration with Dan Yergin and IHS Market. I want to emphasize the report is our responsibility of EFI and IHS Market but with the strong support of Energy Breakthrough, the organization established by Bill Gates to focus on energy innovation.

The context certainly starts by—we all know this but it deserves repeating. Innovation is at the heart of the American success story, driving our economy and security for a long time, and we emphasize that we must continue to place our bet on innovation outcomes rather than prescribed or planned outcomes as has often been the case in other countries, and this remains very wise counsel in discussing clean energy innovation going forward and the massive low-carbon energy economy transformation that we are just at the beginning of.

Accelerating this transition will not be easy. The nature of the business, highly regulated, large capital assets and the like leads to risk aversion. But we emphasize that if we are going to accelerate, the incumbent energy companies must be part of this just as the disrupters, entrepreneurs, must be part of it, and we have to see them as partners in a successful transformation. Part of that involves what we call the platform technologies like edited manufacturing and big data and AI, et cetera. We need to do more to integrate that into the energy innovation challenge.

We have challenges to our preeminence in clean energy innovation. China certainly, for example, with its rapidly growing markets—market pull is a big stimulus to energy innovation, but that highlights even more why we need to focus on this and maintain our preeminence.

Let me highlight—actually, let me also add that we should remember that this energy innovation agenda is equally important for energy security, and I refer the Committee back to the 2014 energy—Modern Energy Security Principles endorsed by the G7 and the EU.

Let me highlight just a few themes from the report. One focus of course is a methodology for looking at our RD&D portfolio itself, and we narrowed down from over 100 to 10 what we consider to be premier opportunities, areas of considerable underinvestment.

Storage, for example, is very prominent, but emphasizing it is about things like new chemistries with earth-abundant elements but it's also about completely new approaches to seasonal storage, as an example, where we are hardly addressing it.

Advanced nuclear. How do we get this unprecedented innovation across the finish line? It's going to require public-private partnerships.

We need to revive and re-look at hydrogen in some sense as an evolution from natural gas to a low-carbon fuel that can be used across multiple sectors, but natural gas itself with carbon capture and sequestration can be a part of that, of that hydrogen economy. That in turn emphasizes that we must focus on the fact that when you go beyond electricity to go to the hard-to-decarbonize sectors like industry, like agriculture, et cetera, they must be part of the solution. I posit they will not be enough even then without adding to it large-scale carbon management. CCUS in the broadest sense is part of that, including areas like biological sequestration, which we are not really doing enough on.

And then finally, and this is very much in Paul's bailiwick, there are the areas which could be enormous breakthroughs but extremely high risk and extremely early in the innovation process, like sunlight-to-fuels, for example, where there are very, very fundamental science issues still to be addressed. So our report kind of paints that picture and hopefully provides some guidance in terms of portfolio construction.

A second point is the scale of investment, and I'll leave that to Jason Grumet to talk about the AEIC, but we do need a very, very large increase in our investment but we all know this is going to come into fiscal headwinds going forward. And so we do recommend a re-look, and I know this Committee has done some of this in terms of new, dedicated funding streams that can help support innovation.

We need to align key policies, programs, players. For example, state regulators play a key role. They must not provide, especially in the competitive markets, headwinds. They need to provide tailwinds for innovation. We discussed that.

We emphasized the importance of regional innovation. And again, we think the Federal Government can do a lot to stimulate this. We need innovative ecosystems in more geographies. We need a set of priorities and opportunities that will emerge in different geographies in different ways. And in fact, the states of our Chair and Ranking Member are examples of how priorities could be set in very, very different ways to address key low-carbon solutions. The national labs that Paul discussed in detail and other FFRDCs could be one of the cornerstones for these regional ecosystems in many ways.

In concluding, there's a clear need for sustaining U.S. preeminence in clean energy innovation, but we need to work at it. This is not going to be automatic. But it's also an enormous opportunity, and this Committee is poised to play a central role.

My colleagues and I remain available to help in any way we can. I look forward to the discussion.

Thank you, Madame Chair.

[The prepared statement of Dr. Moniz follows:]

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Ernest J. Moniz
Founder and CEO
Energy Futures Initiative

Statement of the Honorable Ernest J. Moniz
Before the
Committee on Energy and Natural Resources
U.S. Senate
February 7, 2019

Chairman Murkowski, Ranking Member Manchin and Members of the Senate Committee on Energy and Natural Resources, thank you for the opportunity to appear before you today to discuss the future of energy innovation in the United States.

It was my pleasure to appear multiple times before this Committee during the time I had the honor of serving as the 13th U.S. Secretary of Energy. Throughout my time of service, I found that Members of the Committee from both sides of the aisle came together on numerous occasions to support U.S. energy innovation. I hope that the 116th Congress will continue this tradition.

Much of my career has focused on energy innovation. At MIT, I established the MIT Energy Initiative, which had a significant focus on innovation in a carbon-constrained environment and engaged all of MIT's Schools. As Secretary of Energy, I made clean energy innovation a cornerstone of the Department's initiatives and policy. And now, at the Energy Futures Initiative, clean energy innovation is a pillar of our policy analysis. EFI has produced policy papers on important elements of energy innovation, including the national security foundation for the commercial nuclear energy sector; implementation of the 45Q tax credit program for carbon capture, utilization and storage; expanding the DOE Loan programs to leverage increased innovation in energy infrastructures; and application of blockchain technology to management of energy systems and services.

Importance of Energy 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. Innovation drives job creation, contributes to national security, addresses complex societal challenges and improves our quality of life.

For the past seven decades, the United States has been the global leader in technology and energy innovation. 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.

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The U.S. is undergoing rapid change in the global competitive environment, challenging America's preeminent position but also offering immense opportunity for shaping the inevitable low-carbon global energy future. 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. Nations in denial of climate change as a critical driver of an accelerated clean energy transformation will be left behind.

Accelerating this transformation won't be easy: the U.S. energy system has considerable inertia and risk aversion, since the industry is highly capitalized and must provide essential services all the time. This creates an inherent tension between the energy incumbents and the technology disruptors that must instead be harnessed to advance innovation, with incumbents and disruptors each playing an essential role.

Accelerating the Pace of Energy Innovation

It is in this context that the Energy Futures Initiative and IHS Markit undertook a joint study of the U.S. energy innovation landscape, commissioned by Breakthrough Energy. Yesterday we released the final report, *Advancing the Landscape of Clean Energy Innovation.* Breakthrough Energy asked my colleague and friend Dan Yergin and me to co-chair the study, drawing on our complementary private sector and public sector perspectives on the current U.S. clean energy innovation landscape, with the goal of defining a strategic path forward of national scope. The Executive Summary of the report is attached for inclusion in the hearing record.

Clean energy innovation supports multiple national goals: economic competitiveness, environmental responsibility, energy security and national security. The report describes today's U.S. ecosystem of clean energy innovation from the perspectives of technological potential, investment patterns, institutional roles and public policy. *Advancing the Landscape of Clean Energy Innovation* provides recommendations for accelerating our progress toward a clean energy economy.

Our study was comprehensive in scope, addressing technologies with breakthrough potential; the role of regional clean energy ecosystems; mobilizing increased private sector investment in energy innovation; and the respective roles of federal, state, local and tribal governments. Based on our assessment of the strengths and weaknesses of the clean energy ecosystem, we developed 18 major recommendations for making the ecosystem more effective.

A key finding is the need for increased, and better targeted, public and private sector investment in energy innovation across all stages of the innovation spectrum from fundamental research through commercial scale demonstrations. The study team developed a methodology and set of criteria to examine current and proposed energy technologies for their breakthrough potential. The report examined more than 100 cutting edge energy technologies, focusing on the candidates with significant breakthrough potential, including: advanced energy storage technologies; advanced nuclear reactor technologies; new approaches to decarbonization of industrial processes; electricity systems

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modernization with a focus on the role of grid modernization in enabling smart communities; and large-scale carbon dioxide utilization and management, including new approaches for carbon dioxide removal from the environment where emissions are not otherwise averted or mitigated.

Several groups, including the American Energy Innovation Council made up of large American company CEOs, have argued for tripling federal clean energy investment. This is important, but more than increased funding is needed. The federal energy innovation portfolio—indeed the portfolio across the entire innovation chain—needs to be "all of the above" to match the 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.

The report recommends that the private sector allocate increased investment from the tax savings created by the Tax Cut and Jobs Act to energy innovation, with a particular focus on testing facilities for product demonstration. The analysis also makes clear that disciplined public-private partnership is needed across the innovation value chain to demonstration and initial commercial deployment of critical technologies. The report also recommends a stronger role for strategic philanthropic investors in alignment with government and industry.

The report highlights the need for the federal energy innovation research portfolio to be better managed for performance, regardless of the appropriated amounts. 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.

The report notes that DOE's 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. The current structure also lacks clear direction for supporting all stages of the innovation process from fundamental research through commercial demonstration. 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.

During my tenure as Secretary, I advanced clean energy innovation as the cornerstone of our national energy policy. We combined the science and applied energy R&D portfolios under a single Under Secretary to enable more seamless translation of fundamental science into new energy technologies. We incorporated innovation into the two installments of the Quadrennial Energy Review, a government-wide effort that integrated the energy-related interests of 22 federal agencies. Congressional action on many of the energy infrastructure recommendations demonstrated the broad appeal of analytically grounded policy development. We also updated the Quadrennial Technology Review. We placed particular focus on the role of the DOE National Laboratory system. We created a Laboratory Policy Council to engage the Laboratories in a stronger strategic relationship with Departmental policies and

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programs, established a Laboratory Operations Board to promote more efficient and effective laboratory operations, created the Office of Technology Transitions to accelerate the transfer of new technologies to the private sector and produced the first State of the National Laboratories report. We analyzed the importance of regional innovation systems and our last budget request sought funding for regional structures.

On the international scale, DOE led efforts to revamp and modernize the G-7/EU Energy Security Principles, which provided a focus on the importance of clean energy to energy security. DOE also was in the forefront of the establishment of Mission Innovation, an initiative supported by 23 countries plus the European Commission to double the level of public investment in energy technology innovation over five years.

The report builds on this foundation and expands the focus to all levels of government to align key policies, players and programs in ways that both enhance and accelerate clean energy innovation. At the federal level, the report notes that the fuels-based organizational structure of DOE, which has been in existence since 1979, is not optimized for modern energy systems and needs. It tends to lead to budget allocations by fuel, resulting in gaps and budget distortions, rather than prioritization by innovation potential.

A good case in point is DOE funding for RD&D on advanced grid-scale energy storage technologies. The budget requests for energy storage R&D in each of the past two fiscal years was only $8 million for this key technology area. Congress increased the grid-scale energy storage budget in the electricity office significantly, to $41 million in FY 2018 and $46 million in FY 2019; yet it remains underweighted within a $5 billion total DOE energy RD&D investment portfolio when one considers the needs all the way to seasonal storage. A serious gap currently exists for carbon dioxide removal RD&D (including biological sequestration), which has no obvious organizational home within the current DOE organizational structure, and consequently is not funded at a level commensurate with its need and long-term potential.

The report's assessment of the current landscape in the energy innovation space was not limited to DOE or the federal government. 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. It recommends increased focus on identifying and spreading the use of best practices among the states, and closer alignment of federal and state financial incentives to maximize effectiveness. Expanded policy innovation in state electricity and natural gas regulatory practices also could play an important role in accelerating energy innovation.

The report also notes the importance of nurturing energy innovation ecosystems at a regional scale. 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. Many energy innovation clusters have emerged in the U.S. and are evolving into fully-integrated

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innovation ecosystems, and 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.

A key finding underpinning the work of the study team was the emergence of new technologies outside the energy arena that can enable further innovation in energy applications. Technological developments in digitalization, big data analytics, advanced computing, smart systems, additive manufacturing and robotics have opened the door to a potential new wave of innovation in the energy economy. Combined with socio-economic trends in urbanization and flattening of energy demand, they point to new opportunities for energy innovation, for the emergence of new companies and whole new industries in the energy sector, creation of new and better jobs, new consumer services, more cost-effective energy use and a deeply decarbonized 21st century energy economy.

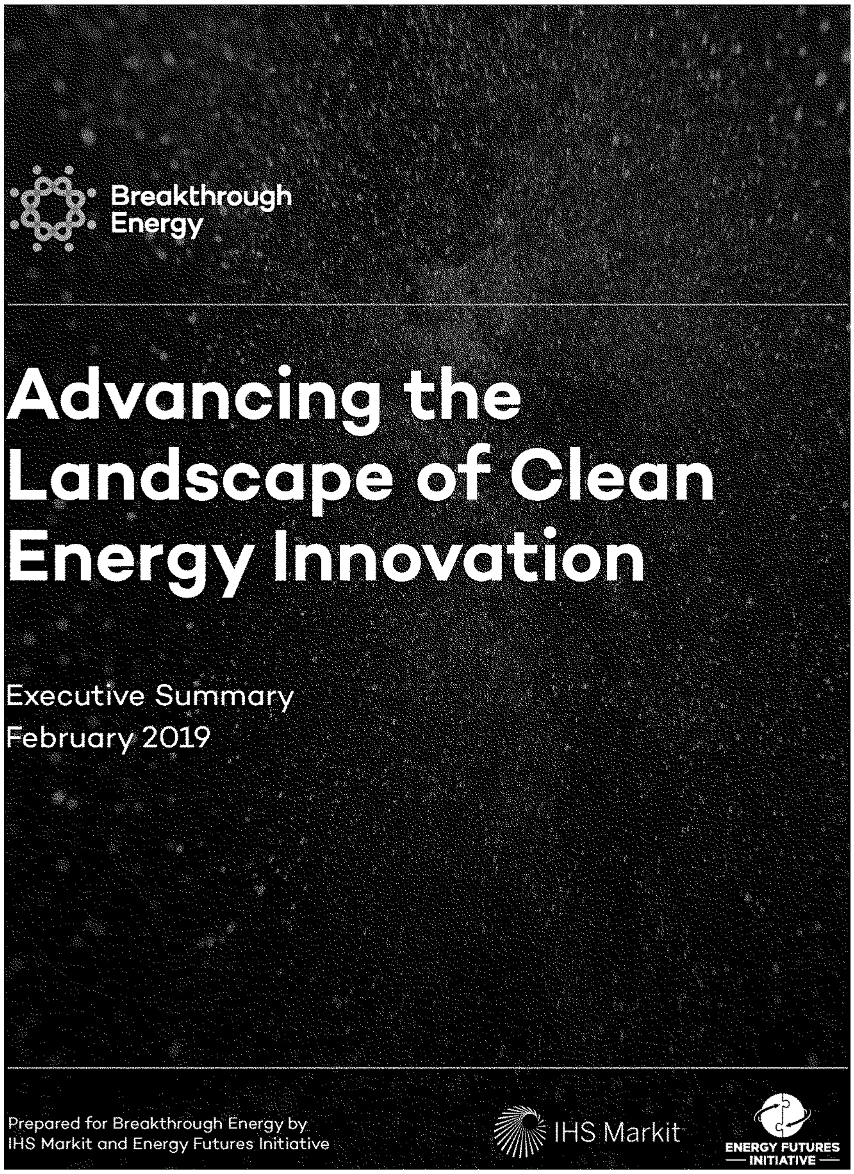
Conclusion

All of this work 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 important Committee. I have always found that Senators from both sides of the aisle work together to support US energy innovation.

Chairman Murkowski, Ranking Member Manchin and Members of the Senate Committee on Energy and Natural Resources, thank you for the opportunity to appear before you today to discuss the future of energy innovation in the United States. I look forward to your questions.

Attachment: *Advancing the Landscape of Clean Energy Innovation*, Executive Summary, February 2019



Breakthrough Energy

Advancing the Landscape of Clean Energy Innovation

Executive Summary
February 2019

Prepared for Breakthrough Energy by
IHS Markit and Energy Futures Initiative

IHS Markit

ENERGY FUTURES INITIATIVE

Foreword

We are pleased to submit our report, "Advancing the Landscape of Clean Energy Innovation." In this report we describe today's U.S. ecosystem of clean energy innovation from the perspectives of technological potential, investment patterns, institutional roles, and public policy.

The report identifies critical strengths and weaknesses of this ecosystem and offers recommendations for making that ecosystem more effective. It examines the different technology readiness stages through which innovation passes and the importance of feedback among those stages. It also discusses the significant opportunities to accelerate the pace of clean energy innovation that are presented by rapid advances occurring today across a myriad of technologies originating outside the energy sector.

We would like to emphasize three observations from our report.

- First, the U.S. has shown over many decades an unparalleled capacity to nurture energy innovation. This capacity reflects a rich and durable collaboration among government, universities, research institutions, industry, and entrepreneurs. This collaboration is grounded in the belief that energy innovation contributes importantly to economic growth, energy security, and environmental stewardship.
- Second, even with our capacity to innovate, and even with the emergence of innumerable technological opportunities, there are significant challenges in moving forward with clean energy technology. These challenges arise from the sheer size and complexity of existing systems, the degree to which these systems are embedded in our economy, and the high public expectations of safety and reliability they must meet. Energy systems traditionally have evolved incrementally.
- Third, these challenges can be met only by building on the collaborative strengths that our ecosystem has already demonstrated. Clean energy innovation depends on a national commitment to technological research; private-sector efforts to develop, apply, and commercialize products incorporating that research; and public policy.

In this report we convey the need for a comprehensive approach involving both public and private sectors in order to expand the current landscape of clean energy innovation and accelerate its processes. We hope that our report contributes to an understanding of the challenges presented and the approaches needed to address those challenges effectively. There is no final word on the subject. We see this report as a contribution to a continuing national dialogue and hope that it will stimulate further discussion, understanding, and action.

We are grateful for the opportunity that Breakthrough Energy and its partners have provided to explore this topic and recognize their commitment to advancing a meaningful and timely national dialogue. We hope that our report informs an appreciation of the complexity, reach, inherent dynamism, and promise of the U.S. clean energy innovation landscape and of the leadership that the United States can continue to provide.

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Former U.S. Secretary of Energy
Project Co-Chairman

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Executive Summary

The United States has been at the forefront of energy innovation for many decades. One of the most important reasons is the unique and extensive collaboration along the entire chain of innovation, from basic research to deployment, that engages the federal government, national labs and research institutes, universities, private sector, and state and local governments. This system has given the U.S. a global advantage for many decades.

The increasing focus on clean energy technology solutions and the potential for disruptive changes in energy systems points to the need for an objective review of the current clean energy innovation ecosystem. How does the clean energy innovation system work? What are its strengths and weaknesses? Is it up to the challenges? And how can it be improved and accelerated?

These are the questions that this study seeks to answer. Significant opportunities for clean energy innovation are presented by the changing U.S energy supply profile; by advances in platform technologies such as digitalization and big data analytics; by expansion of electrification in the transportation and industrial sectors of the U.S. economy and the resulting electricity dependence of these sectors; by increases in urbanization and the emergence of smart cities; and by broad social and economic forces pushing to decarbonize energy systems in response to the risks posed by global warming and associated climate change.

Clean energy innovation supports multiple national goals: economic competitiveness, environmental responsibility, energy security, and national security. In serving these goals the need to address climate change is the challenge that calls most urgently for accelerating the pace of clean energy innovation.

Key features of energy systems, however, impede accelerated innovation. Energy is a highly capitalized commodity business, with complex supply chains and established customer bases, providing essential services at all levels of society. These features lead to systems with considerable inertia, focus on reliability and safety, aversion to risk, extensive regulation, and complex politics. Existing innovation processes face challenges as they work within these boundary conditions. The rapid pace of international energy investment, the commitments of most countries to Paris climate goals, and the ability of some countries such as China to rapidly increase clean energy investments challenge the preeminent position of the U.S. in clean energy innovation.

Successful clean energy innovation on a large scale in the U.S. requires alignment of key players, policies, and programs among the private sector, the federal government, and state and local governments. This report considers these alignment needs through an assessment of the roles of these various groups. It also identifies critical clean energy technologies. It further suggests the value of regional efforts to advance innovation, and discusses ways in which federal tax policy could accelerate innovation. The report offers recommendations in each of these areas.

The Role of the Private Sector

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. At the same time, fundamental dynamics of the energy sector present significant challenges to clean energy innovation, stemming from basic industry characteristics and from the difficulty of capturing the full value of clean energy through market transactions alone. Innovators in clean energy face significant challenges in securing financial support and in demonstrating the compatibility of new technologies with existing systems. Over the past several years, venture capital has reduced its engagement in clean energy innovation, and traditional energy companies are exploring new models and mechanisms for innovation and investment.

While the initial stages of clean energy innovation are supported by a diverse, world-class set of U.S. research institutions, the innovation support system weakens as inventions move toward commercialization. The clean energy incubators that have emerged in recent years have so far tended to support software solutions. The availability of testing facilities for product demonstration is limited by the small number of facilities suitable for sustained testing and by their specialization.

Because of the energy system's long cycles of adoption, a broad range of approaches should be deployed to make it easier for adopters to understand, anticipate, and support the innovations that are being generated at the early stages of the innovation process. These efforts include, on the part of energy companies, open innovation, standardization of procurement requirements, encouragement of innovation testing either through dedicated evaluation staffs or through performance metrics, and active outreach to become familiar with innovations at the development stage or earlier. They include, on the part of innovators, early attention to the needs of adopters as indicated by expressed needs and by the past performance of innovation efforts.

Investments are needed from foundations and from federal, state, and local governments to expand the availability of open-access testbeds and strengthen the effectiveness of incubators in accelerating commercialization of innovative technologies. Some of these investments could fund research into best practices and performance results of incubators and testbeds and of state and local programs supporting innovation.

Because clean energy innovation incentivizes only modest financial investments at precommercial stages, and because strategic corporate investment is focused primarily on those innovations recognized as useful to business objectives, strategic philanthropic investors and coalitions of industry investors with long-term horizons could play an important role in identifying and supporting promising technology ventures that are otherwise not commercially viable in the near term.

Recommendations for Near-Term Actions

- Adopters of new technology, such as utilities, should consider a variety of approaches to support the innovations that are being generated at the early stages of the innovation process, including: open innovation; standardization of procurement specifications; encouragement of innovation testing (either though dedicated evaluation staffs or through performance metrics); and active outreach to become familiar with innovations at the development stage or earlier.
- Strategic philanthropic investors and coalitions of industry investors with long-term horizons should play an active role in identifying and supporting promising technology ventures that are otherwise not commercially viable in the near term.
- Foundations, as well as federal, state, and local governments, should make investments to expand the availability of open-access testbeds and incubators to accelerate commercialization of innovative technologies (e.g. Cyclotron Road).

Technologies with Breakthrough Potential

A shared agenda of primary technology objectives can help ensure that programs pursued by multiple stakeholders in the clean energy space are timely, durable, and mutually supportive. It can give entrepreneurs and creative innovators a framework for assessing the prospects of a particular area of initiative and the steps needed to sustain critical innovations over long time spans, and it can give corporate adopters, financial investors, and policymakers visibility into the evolving future of clean energy.

A four-step methodology is suggested for identifying breakthrough technologies to address national and global challenges and help meet near, mid- and long-term clean energy needs and goals. These steps consider technical merit, potential market viability, compatibility with other elements of the energy system, and consumer value. Application of these considerations to a list of 23 potential technology candidates yields a key technology shortlist:

- **Storage and battery technologies**
- **Advanced nuclear reactors**
- **Technology applications for industry and buildings as sectors that are difficult to decarbonize**
  - Hydrogen
  - Advanced manufacturing technologies
  - Building energy technologies
- **Systems: electric grid modernization and smart cities**
- **Deep decarbonization/large-scale carbon management**
  - Carbon capture, use, and storage at scale
  - Sunlight to fuels
  - Biological sequestration

Recommendations for Near-Term Actions

- Federal investments in energy research, development, demonstration, and deployment (RDD&D) should be planned within a portfolio structure that supports potential breakthrough technologies at various timescales. There should be special focus on a critical subset of those technologies deemed to have very high breakthrough potential.
- Federal energy RDD&D portfolio investments should adopt a formal set of major evaluation criteria—such as technical merit, market viability, compatibility, and consumer value—with specific metrics for each criterion. These criteria should be used to prioritize programming and budget allocation decisions, as well as to develop public-private partnerships.
- Public and private sector stakeholders should collaborate in planning for and piloting of emerging technologies. A key component of these efforts is systems-level development plans that delineate technical challenges and risks; R&D pathways; cost and schedule assumptions; institutional roles (including public-private partnership opportunities); pathways to commercialization and diffusion; economic benefits; and consumer value.
- The Department of Energy (DOE) should lead a national effort to update the Basic Research Needs Assessments, originally initiated in 2001, to inform the assessments of emerging technologies with breakthrough potential, as well as the development of system-level roadmaps.

The Federal Government Role

The Federal government has long played a central role in supporting energy innovation. Through research grants, loan programs, tax incentives, laboratory facilities, pilot programs, and public-private partnerships, it has set the direction and pace of energy R&D, with profound impact on the national economy.

The principal agency funding clean energy innovation is the Department of Energy (DOE), which administers about 75 percent of all Federal energy R&D spending. DOE performs its role in partnership with its 17 national laboratories, academia, states, regions, other agencies, and the private sector. There are, however, several other Federal agencies with significant clean energy innovation budgets, including: the Department of Defense (DOD), the Department of Transportation (DOT), and the Department of Agriculture (USDA). Portfolios at these agencies are mission-focused, however, as opposed to being broadly based across all energy sectors.

As the primary Federal funder of energy R&D, DOE has played a critical role in changing the U.S. energy landscape over several decades. Shortly after its establishment in 1977, DOE characterized U.S. shale basins and supported the development of key drilling technologies that enabled horizontal drilling. It has had an ongoing and central role in developing supercomputing, an enabling technology for digitalization, artificial intelligence, smart systems, and subsurface characterization. Its investment in phasors and sensors support the smart grid. The Advanced Research Projects Agency — Energy (ARPA-E) – a DOE program —

has led to the creation of dozens of clean energy start-up companies which have raised more than $2.6 billion in private-sector follow-on funding.

However, DOE's performance in advancing clean energy innovation would benefit from several institutional modifications. For example, the fuels-based organizational structure of the DOE, which has been in existence since 1979, is not optimized for modern energy systems and needs. It tends to lead to budget allocations by fuel, rather than prioritization by innovation potential.

The lack of long-term stable and predictable funding is also a concern for future R&D efforts at DOE. Although the Federal clean energy RD&D portfolio is significant (approximately $6.4 billion in FY 2016 if expenditures by all Federal agencies and by DOE on basic science research are included), some prominent government and industry leaders have recommended the need for funding levels at two to three times the current levels based on the energy industry's current value to the economy (roughly $1.37 trillion). While the Bipartisan Budget Act of 2018 (BBA) set new caps for discretionary spending that are as much as 25 percent higher than the Administration's budget — providing considerable headroom for near-term increases in spending for clean energy innovation — this agreement extends through FY 2019 only. The highly uncertain budget outlook for FY 2020 makes it difficult to plan an effective energy innovation portfolio focused on technologies with high breakthrough potential.

Recommendations for Near-Term Actions

- Congress and the Administration should initiate efforts to reorganize the Federal energy RDD&D portfolio and the Department of Energy toward a fuel- and technology-neutral structure that (1) aligns with the highest priority opportunities, (2) enables systems-level integration, and (3) avoids gaps in crosscutting programs.
- Congress and the Administration should consider dedicated funding sources for energy innovation as a means to ensure predictable and increasing levels of clean energy RDD&D funding based on international and cross-sectoral benchmarks.
- Federal policymakers should expand demonstration projects for key breakthrough technologies, while ensuring accountability via stage-gated project management, risk-based cost sharing, and assignment of demonstration project oversight to a single office within DOE.
- DOE and other agencies, as appropriate, should increase collaboration with the private sector and academia, including:
  - Instituting a multi-year and multi-agency portfolio planning process with broad-based stakeholder involvement from the private sector and academia.
  - Expanding use of prize authority to foster competition and open innovation.
  - Simplifying public-private partnerships with flexible financial vehicles like Technology Investment Agreements.

The Role of State, Local and Tribal Governments

State and city governments have regulatory authority over most of the myriad consumer, commercial, and industrial activities that collectively shape the country's patterns of energy use. They play central roles in advancing clean energy innovation, above all by creating markets for the application of clean energy technologies and encouraging diffusion of those technologies through supportive financial mechanisms.

Cities are crucial clean energy innovation testbeds. Urbanization trends make "smart cities" especially important as technology platforms for a clean energy future. Enhanced federal-state-city, public-private, and private-private partnerships can help unleash smart city innovation for tailored urban services, mobility, and standard-of-living improvements in the 21st century. "Smart" improvements could also provide significant value to rural communities by enabling decentralized generation and manufacturing, improving energy efficiency, and supporting economic development.

The contribution of state, local, and tribal governments to clean energy innovation could be further strengthened by development of program best practices and standardization, capacity and resource enhancement, increased funding, and modernization of ratemaking and business models. Programs that support and promote clean energy and energy innovation require significant state and local administrative resources and expertise; offices and officials that run them often have limited resources. Also, traditional ratemaking policies and methodologies at the state and local level can act as barriers to deployment of innovative energy technologies due to their reliance on proven track records associated with reliability and cost savings.

Recommendations for Near-Term Actions

- States should consider adopting technology-neutral clean energy portfolio standards and zero-emissions credits in order to strengthen markets for clean energy innovation — to include renewables and other forms of zero or low-carbon energy.
- State and local regulatory agencies should consider new ways in which existing ratemaking principles could be adapted to incentivize utilities to deploy established clean energy technologies, test emerging energy technologies, and realize value from behind the meter technologies.
- States should collaborate to identify best practices in the deployment of clean energy technologies, including financing mechanisms, consumer protections and equitable sharing of benefits among all socio-economic groups and geographic locations.

The Role of Regional Clean Energy Innovation Ecosystems

Many of the innovation opportunities and risks faced by the energy sector are highly regional in nature and are appropriately managed by strategies tailored to each region's specific needs. Strong regional relationships, for example, are observable among innovation, job creation, and technology deployment in the solar and wind energy industries.

Many energy innovation clusters in the U.S. are in the process of evolving into fully integrated innovation ecosystems. While federally funded RDD&D historically has not been well connected to state and regional economic development, activating these regional clusters to break down the barriers among federal, state, and local resources will create new synergies. National labs could serve as anchors for these efforts. While Federal support is important, regional leadership is critical. State and local governments, the private sector, universities, and philanthropies all have important roles in developing the particular strengths and shaping the particular contributions of regional innovation ecosystems.

Recommendations for Near-Term Actions

- Universities, private industry, philanthropies, state and local governments, and DOE should seek to expand and strengthen incubator capabilities within regional clusters to provide additional tools to enable innovators to conduct R&D and prototyping.
- DOE national laboratories, other federal laboratories, and Federally Funded Research Centers (FFRCs) can serve as anchors for regional clean energy innovation — and should be given sufficient flexibility in the expenditure of discretionary funds to support regional clean energy innovation options.

Mobilizing Increased Private Sector Investment in Energy Innovation

For U.S.-based entities, budget caps, reduced discretionary spending, and the Tax Cuts and Jobs Act (TCJA) will put downward pressure on Federal spending but will incentivize corporations to increase significantly business investments over the next decade (with estimates of up to $1.5 trillion in incremental new investment, some of which could be targeted to energy innovation and infrastructure. Attracting these funds into clean energy innovation will depend on success in aligning the various elements of the innovation ecosystem discussed in this report: public policies that encourage a robust pipeline of research and that create markets for clean energy applications, combined with private-sector institutions that facilitate the commercialization of innovations.

The TCJA left unchanged the existing tax credits for renewable energy (wind, solar and geothermal), but did not extend the so-called "orphan" tax credits for fuel cells, combined heat and power projects, geothermal heat pumps, and new nuclear power plants. Most of these credits had expired at the end of 2016. The Bipartisan Budget

Act of 2018 (BBA), passed in February, modified and extended the nuclear power PTC; other credits were extended only through 2017 and their fate is uncertain.

In addition, the BBA included expanded provisions for carbon dioxide (CO_2) capture, utilization and storage (CCUS). The new 45Q provisions have the potential to significantly enhance the development and market diffusion of CCUS technologies and processes in both industrial and power applications, creating commercial opportunities both in the U.S. and abroad. The provisions provide greater market and financing certainty to help attract additional follow-on investment from the private sector.

Recommendations for Near-Term Actions

- DOE should set aside a small portion of its existing applied energy RDD&D funding to support accelerated de-risking of near-commercial innovative energy technologies and systems on an accelerated basis, to make these options more attractive for private capital investment.
- The new Section 45Q provisions expanding tax credits for carbon dioxide (CO_2) capture, utilization, and storage (CCUS) have the potential to significantly enhance the development and market diffusion of CCUS technologies and processes in both industrial and power applications, creating commercial opportunities both in the U.S. and abroad. Congress should consider additional measures to facilitate and accelerate CCUS deployment, including addressing uncertainties regarding long-term post-injection carbon management, monitoring, reporting and verification.

The CHAIRMAN. Thank you so very much. I appreciate your contribution.

Ms. Wince-Smith, welcome.

STATEMENT OF DEBORAH L. WINCE-SMITH, PRESIDENT & CEO, COUNCIL ON COMPETITIVENESS

Ms. WINCE-SMITH. Thank you, Chairman Murkowski, Ranking Member Manchin and members of the Committee, for the opportunity to address our nation's innovation imperative.

I, too, would like to thank Secretary Moniz for his tremendous leadership, Under Secretary Dabbar and the other members of the panel.

I will focus my remarks on today's reality; namely, that access to low-cost, abundant domestic energy and increasing energy efficiency and productivity coupled with the emergence of U.S. advanced manufacturing capacity has created a tremendous economic opportunity for our country and, since 2008, a significant positive decoupling of energy use from economic growth. This opportunity calls for national leadership, investment and public-private partnerships to capitalize on this nexus of energy abundance and our manufacturing renaissance supported by America's great research universities, national laboratories, global industrial enterprises, emerging new companies and skilled workforce.

Unparalleled advances in science and technology are transforming our economy and the energy systems that power and enable its productivity. These advances are ushering in new industries, disrupting the old and up-ending the skill sets required for our citizens to prosper in a relentless world of competition and transformation.

The digitization of the economy is moving ahead full speed with smart sensors, the tsunami of data, deployment of AI and autonomous systems, the emergency of 5G telecom infrastructure, next-generation microelectronics moving us beyond Moore's Law. Advanced manufacturing processes and new materials are driving the emergent battery technology required for all energy sources to power an interoperable smart grid system.

Yet we face formidable challenges: challenges that demand a national commitment to optimize our innovation system, one weakened by chronic underinvestment in federal R&D, hampered by outdated innovation-hostile regulation, limited by lack of access to patient long-term capital to support innovation cycles from startup to scale-up, and deficient, degrading infrastructures such as interstate transmission.

Of both economic and national security concern are critical technology startups supported with federal investment that have produced tremendously valuable intellectual property, and many are systematically being acquired by Chinese companies' investors. While U.S. investors stay on the sidelines, skilled jobs and manufacturing are moving to China, all incubated by the U.S. taxpayer.

As the U.S. advances its energy and production distribution systems with notable progress in energy efficiency, the Council's recent report, Secure, asserts that cybersecurity and cyber resiliency must be at the center of grid modernization and nuclear plant monitoring. With 90 percent of our grid in the private sector, companies must adopt cyber hygiene, best practices, NIST standards, and the deployment of proven technologies to harden digital systems from pernicious cyberattacks. Underpinning all of these challenges is an overarching workforce skills gap that requires systemic reskilling. The Council's report, Accelerate, sets forth a call to action, a road map to turbocharge the competitiveness of the U.S. energy and manufacturing enterprise.

First, the U.S. must level the federal and state regulatory playing fields to capitalize on the potential of nuclear energy and new technologies such as mini modular reactors, key components of a low-carbon clean energy portfolio. Utilities must be allowed to recoup a percentage of R&D investments in rate increasing. Modernizing the grid must, of course, encompass cyber resiliency.

Second, we must lead in research and commercialization at scale of the critical technologies driving global transformation for our society, economy and national security. The Made in China Manifesto calls for massive investments in AI, supercomputing, gene editing, nanotechnology, blockchain, and yes, clean energy, not to mention microelectronics and 5G. We must invest and deploy the enabling digital infrastructure of the future including our leadership in advanced computing, exascale and the frontiers of quantum computing. We must expand our strategic national network of innovation hubs and regional testbeds such as Argonne Labs' Joint Center for Energy Storage, Berkeley Lab's Cyclotron Row, Lawrence Livermore's High Performance Computing for Manufacturing, Oak Ridge National Lab's manufacturing demonstration facility and PNNL's Good Modernization and Resiliency Center.

Third, we must ramp up our game in workforce upscaling in concert with growing the number and diversity of a STEM-enabled workforce. The U.S. is at a critical moment with systemic long-term productivity decline and the myriad of challenges I have touched upon. It is a time to reimagine and build a flexible, dynamic, responsive national innovation system that includes and rewards all Americans and that ushers in a new era of inclusive prosperity and security.

The Council on Competitiveness is launching a national commission on innovation and competitiveness frontiers to optimize the policies and spur the initiatives to propel us toward that future, looking at the acceleration of the development and deployment of emergent technologies, leveraging the future of production, sustainable consumption in work, and optimizing the innovation systems that are hostile or enabling, such as finance, regulation, standards, competition policy, trade, et cetera.

Madame Chairman, Ranking Member Manchin, we look forward to working with you and the members of the Committee to shape this important national initiative. Thank you for the opportunity to be with you today, and I look forward to answering any questions.

[The prepared statement of Ms. Wince-Smith follows:]

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Council on Competitiveness

Testimony before the United States Senate Committee on Energy and Natural Resources

SD-366—9:30AM

Deborah L. Wince-Smith
President & CEO, Council on Competitiveness

February 7, 2019

Introduction

Thank you, Chairwoman Murkowski, Ranking Member Manchin and members of the Committee for inviting me to discuss how we can all work together to drive innovation in a way that allows the U.S. economy and its citizens to capitalize on America's energy opportunity.

My name is Deborah Wince-Smith and I am the President and CEO of the Council on Competitiveness (Council). The Council is a non-partisan membership organization of 150 CEOs, university presidents, labor leaders and national laboratory directors founded in 1986 to develop the impactful policies and actions that will boost U.S. productivity, drive inclusive prosperity for every American and ensure the success of U.S. goods and services in the global marketplace.

The Council is led by a tremendous Board of Directors including our chairman, Dr. Mehmood Khan, the vice chairman and chief scientific officer of global research and development at PepsiCo, Inc., our industry vice chair, Mr. Brian Moynihan, the chairman of the board and Chief Executive Officer for Bank of America, our university vice chair Michael Crow, the president of Arizona State University, our labor vice chair, Mr. Lonnie Stephenson, international president of IBEW, and our Chair Emeritus, Mr. Sam Allen, CEO of Deere and Co.

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

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

With global competition accelerating and revolutionary technological advances unfolding, a dynamic cycle of creation, growth, disruption, decline and destruction will continue into the future as economies at home and abroad adapt to the changing landscape. There will be opportunities for new businesses, industries and jobs, but there will also be challenges for some people and communities as industries shift, labor markets are disrupted and jobs change.

We are witnessing the unfolding and rapid advancement of some of the greatest revolutions in science and technology in history: a new phase of the digital revolution characterized by vast deployment of sensors, the Internet of Things, artificial intelligence (AI) and the big data tsunami; biotechnology and gene-editing; nanotechnology; and autonomous systems. Each of these technologies has numerous applications that cut across industry sectors, society and human activities. Each is revolutionary, each is game-changing in its own right. But they are now colliding and converging on the global economy and society simultaneously, with profound implications for U.S. economic and national security. These technologies are disrupting industries across the globe and altering the patterns of society and many dimensions of everyday life.

Looking specifically at the energy sector, it's clear we are moving toward a low carbon world. For countries and companies, the ability to leverage technological change for economic impact is fundamental to their competitiveness and economic success. In this "Sputnik Moment," the Council on Council on Competitiveness believes the United States must make much greater and more strategic use of science and technology, and that innovation must rise on the national economic agenda.

The Council has a long history in shaping America's policy agenda in a way that fosters innovation and competitiveness.

<u>The Council on Competitiveness in the Energy Space</u>

In pursuing the Council's mission, our distinctive, multi-stakeholder membership has consistently agreed on a key principle: energy is everything.

In 2006, the Council released its landmark private sector report, *Innovate America* that helped spur legislative action leading to the passage of the bipartisan America COMPETES Act two years later. *Innovate America* connected the dots between research and development, STEM education and 21st century infrastructure as the underpinnings to U.S. innovation leadership. The report also called out manufacturing and energy—access to energy, the sustainable production of energy and the deployment of a wide-range of energy resources to reinvigorate America's industrial base—as critical, "over-the-horizon" issues the nation would have to confront to ensure long-term national competitiveness.

But even as we began making the case in 2007 and 2008 that energy security, innovation and sustainability were the cornerstones of future competitiveness, the nation's—and the world's—energy landscape was changing radically.

By 2007, America's growing dependence on imports to meet energy needs had become a major factor in the trade deficit, accounting for over 45 percent of the total figure. Dependence on foreign oil translated into an outflow of $439 billion dollars annually, posing a serious challenge to U.S. national and economic security. At the same time, private sector and many state leaders were beginning to embrace the imperative for sustainability and looking for ways to transition to a low-carbon world.

To explore further this changing paradigm, the Council developed and leveraged a strong partnership with the Department of Energy that has spanned multiple administrations, both Republican and Democratic, to launch in 2007 the Energy Security, Innovation and Sustainability Initiative. This strategic partnership recognized the critical linkages among security, innovation and sustainability and their profound impact on future U.S. productivity, standard of living and global market access. We forged consensus on an agenda for change that sought to underpin a smooth and timely energy systems transition and to ignite a brilliant new era of energy innovation, market success, job creation and productivity. A key overarching recommendation cited for the U.S. to develop and utilize all sources of energy sustainably and to level the playing field on subsidies and incentives.

Then, the landscape shifted again as the United States began a more earnest exploration toward low-carbon natural gas, coupled with the rapid expansion of renewable energy. Facing this new energy reality, the Council began in 2013 an effort to look at the economic opportunity at the intersection of energy and manufacturing. The American Energy & Manufacturing Competitiveness (AEMC) Partnership was a four-year partnership between the Council and the Department of Energy Office of Energy Efficiency and Renewable Energy to identify public-private partnerships and other actions that could enable America to build on this distinctive time in its energy history to dramatically increase its energy, manufacturing and economic competitiveness.

There have been many tangible outcomes from the AEMC Partnership's research agenda, four national summits and nearly 10 regional dialogues across the country. These outcomes include but are not limited to:

- Bolstering America's manufacturing competitiveness intelligence through the creation of the nation's first-ever "Clean Energy Manufacturing Analysis Center."
- Rebuilding America's shared manufacturing innovation infrastructure with nearly $1 billion invested publicly and privately during the AEMC's 4-year trajectory, including:
    - Five Department of Energy related National Network of Manufacturing Innovation Institutes;
    - Two new Manufacturing Development Facilities; and
    - A new Energy Materials Network.
- Unleashing national laboratories to advance manufacturing innovation by:
    - Proposing and helping to develop new, High Performance Computing for Energy, Manufacturing and Materials programs at the Department of Energy; and
    - Defining and launching a new Technologist in Residence Program for the national laboratory infrastructure.

A key part of this effort was a closely-related initiative undertaken with Secretary Moniz, who I'm honored to be joined by today on this panel, to create a policy and action roadmap to drive energy productivity across nine key industry sectors. *Accelerate Energy Productivity 2030*, created a viable plan to double U.S. energy productivity from 2010 levels by 2030.

In continuation of this effort to improve industrial energy use, the Council last year partnered with Third Way and the American Federation of Labor and Congress of Industrial Organizations (AFL-CIO) to release *Industry Matters*. The report laid out a number of clear, achievable pathways to saving energy, increasing competitiveness and cutting carbon in U.S. industry, including wider use of industry best practices, increased deployment of existing technologies and accelerated innovation of new technology solutions.

The most recent milestone in the Council's journey to drive competitiveness and prosperity was the October 2018 release of a policy agenda designed to turbocharge America's manufacturing capabilities, improve America's competitiveness and unleash a new wave of productivity, prosperity and resilience for all Americans. *Accelerate* included the critical findings and recommendations of the Energy and Manufacturing Competitiveness Partnership (EMCP)—a three-year effort led by a C-suite Steering Committee which brought together more than 300 experts and practitioners across nine dialogues to assess the economic opportunity at the nexus of energy and manufacturing.

Accelerate looked critically at the cross-section between energy and manufacturing, identifying challenges, opportunities and policy recommendations that impact America's prosperity, productivity and security.

America's Energy Opportunity

The EMCP posited that America finds itself facing a new, promising frontier shaped by two powerful transformations working in tandem. The first is a generational re-emergence of advanced and highly productive manufacturing capacity in the United States. This revolution in production is being driven by a number of technological developments. Virtual design through modeling and simulation using advanced computing, for example, will accelerate innovation and product development, while dramatically reducing costs and risks and allowing America to maintain its competitive edge in high performance computing capabilities. And 5G capabilities will revolutionize autonomy and connectivity, bringing the concepts of smart cities, driverless vehicles and smart factories to life.

The second major transformation occurring in the United States is an increasing abundance of innovative, sustainable, affordable and domestically-sourced energy. Coupled with increases in energy productivity and efficiency, this transition from scarcity to abundance has allowed for the decoupling of energy use from economic growth. In fact, since 2008, primary energy usage in the United States has shrunk 1.7 percent, even as GDP has accelerated by 15.3 percent. The ability to capitalize on these transformational shifts will be paramount for American competitiveness now and in the decades to come.

At the same time, though, the United States faces a number of challenges to its global leadership and its ability to capitalize on the energy opportunity. Much like roads, rail and power plants were essential for the Industrial Age, infrastructure that supports knowledge creation and technology development is vital for the 21st century economy and U.S. success in innovation-based global competition. But, across the system, core scientific and technological capabilities are potentially at risk due to deficient and degrading infrastructure.

For example, the Department of Energy (DOE) has a vast portfolio of world-leading scientific infrastructure and production assets developed over the past 75 years, including 17 national laboratories. With a replacement plant value of more than $130 billion, the land, facilities and other assets that comprise this infrastructure represent some of America's premier assets for science, technology, innovation and security. This infrastructure must be maintained and upgraded.

Industrial consumption and a heavy reliance on shale gas has created growing pressure on the extraction infrastructure, driving the demand for alternative, clean sources of energy from renewables to nuclear. Yet, America's regulatory infrastructure is failing to keep pace with innovation as outdated policies often double the construction time of nuclear plants and offer investors only long-term returns on wind and solar investments.

As the United States continually advances and modernizes its energy systems, efficiency is sometimes prioritized over security, making grid and nuclear plant monitoring a significant concern. And, with nearly 90 percent of America's energy grid operated by private companies, the vulnerability of the grid to cyberattacks and operational disruption is a significant threat to productivity and livelihoods. Failure to comply with rules put in place to secure the electric grid—as in the recent case of Duke Energy, which is facing a record $10 million fine for numerous violations of regulations aimed at preventing physical and cyber-attacks—poses a serious risk to the security and reliability of America's electric grid.

In addition to these infrastructure and security concerns, the financial challenges across the spectrum from start-up to scale up are posing a serious threat to U.S. leadership in technological innovation—something first identified by the Council's 2011 report, *Make*, and highlighted by examples of companies such as A123, a high-flying U.S. battery start-up now owned by the Chinese. The U.S. must ensure access to long-term patient capital through mechanisms such as a clean energy bank that lies outside of the traditional venture model, which is ill-equipped to address the scale and scope of major energy projects. Added to that, America's lead in venture capital is shrinking, further diminishing its role as a driver of technology and innovation globally. In 1992, U.S. investors led 97 percent of the $2 billion in venture finance, and accounted for about three-quarters just a decade ago. However, in 2017, U.S. investors led 44 percent of a record $154 billion in venture finance, with Asian investors accounting for 40 percent. And federal investment in basic research and the absence of a coordinated, defined research agenda to guide insufficiently-funded research and development are limiting the potential for advancement in key sectors.

Underpinning these obstacles is a growing skills gap exacerbated by shifting workforce demographics. With the pace of innovation accelerating rapidly, the pressure to create a workforce with the skills needed to take on the jobs of the future is constantly mounting. Automation—robots, machines, devices, sensors and software—is increasingly capable of doing routine tasks that have comprised millions of American jobs. About five million jobs in manufacturing were lost from 2001-2010, making room for new, higher-skill manufacturing jobs to take their places in a labor market that rewards well-educated workers who can perform non-routine work and complex tasks. But the reskilling of workers will be essential to meeting the ever-changing needs of the U.S. and the global marketplaces.

While all this is happening at home in the United States, global competition is ramping up as countries around the world realize the advantages of investing in a strong innovation ecosystem. While traditional U.S. competitors such as Germany, Japan, France and the U.K. continue to be strong R&D performers working at the leading edge of technology, many emerging economies seek to follow the path of the world's innovators and transform into knowledge-based economies whose economic growth is driven technology and innovation. Most notable for its rapidly strengthening position, China poses an especially formidable and growing strategic competitive challenge, having more than doubled its investment in R&D since 2010 and positioning itself to outpace the United States by the end of this decade. And leadership in clean energy is clearly a priority as evidenced by their efforts in areas such as solar.

As nations begin to recognize the advantages of investing in a strong innovation ecosystem, the United States must re-prioritize science and technology to remain a global leader.

Fostering U.S. Leadership in Energy Innovation

In response to these challenges, the Council developed, and put forth in *Accelerate*, a "call to action" to turbocharge the U.S. manufacturing renaissance in an era of energy abundance. *Accelerate* presents a road map for decision-makers and calls upon stakeholders across the economy to engage and leverage the seminal opportunity the current landscape has created and catalyze a new wave of productivity and prosperity.

Across its recommendations, *Accelerate* emphasizes the following key themes and specific recommendations:

1. The United States cannot compete globally without **establishing the next-generation physical, regulatory and financial infrastructure needed to support the nation's advanced energy and manufacturing enterprise.**

By shifting focus toward innovation, nuclear plants have been able to increase operating capacity from 60 percent to more than 90 percent in the last 30 years. Yet, a recent study by the Nuclear Energy Institute found that oil, gas, hydro, solar, wind and biomass received more than 90 percent of all economic incentives—tax policies, regulation, research and development, market activity, government services and disbursements—

provided to the energy industry since 1950. By leveling the regulatory playing field, the United States can capitalize on the tremendous potential of nuclear energy—including advanced small modular reactors—to be a critical piece of a lower carbon energy portfolio. Policymakers must also work to catalyze innovation in the utility sector by allowing utilities to recoup a percentage of investments in R&D through rate increases.

More broadly, the federal government must ensure states and other entities have the flexibility to propose and implement innovative regulatory models and explore new technologies needed to support the advanced energy and manufacturing enterprise. This means encouraging state and local governments to continue experimenting with new regulatory frameworks to test and evaluate the viability of disruptive technologies from autonomous vehicles to next-generation nuclear power.

With regard to physical infrastructure, we must break the cycle of incremental infrastructure improvements to spur creative and forward-looking approaches to the movement of goods, services and people. This means modernizing the electric grid and facilitating the interoperation of smart grid technologies in tandem with ensuring their cyber resilience.

2**. Federal investment in basic research at a minimum of 1 percent of GDP** is essential to American competitiveness.

While the nation still leads the world in research and development spending, it now trails ten European and Asian countries in R&D spending per unit GDP. Since the early 1960s, federal support for R&D has declined from nearly 2 percent of GDP to 0.8 percent. R&D funding from the private sector has steadily increased over that same time frame, but the private sector, with shorter time horizons, places far less emphasis on basic research than the federal government. That pattern has grown stronger in recent decades. Between 2010 and 2016, U.S. basic research as a percent of GDP declined by 8 percent. Increasing investment in basic research is essential to building and maintaining a world-class innovation-based economy.

3. Ensuring **U.S. leadership in critical technologies** is not only an issue of competitiveness but an issue of national security.

Computing, big data and autonomous systems are converging in the field of AI. AI will be among the most disruptive technologies of the 21st century. It has been estimated that AI could contribute $15.7 trillion to global GDP by 2030. The nation that leads in AI—in its development, application and deployment—will lead a massive global transformation of the economy, society, national security and how we live our lives.

In order to remain competitive, the United States must also continue the quest to develop a capable exascale ecosystem with the ability to advance scientific discovery and strengthen national security. And leadership in quantum information science and our ability to apply this technology to grand challenges will be essential to improving America's industrial base, creating jobs and ensuring economic and national security.

5G technology will offer higher speeds and lower latency making it one of the fastest, most robust technologies to date. 5G will enable more resilient critical infrastructure, technologies like state-of-the-art radar systems and cutting-edge communications on land and in space. It will unlock the door to innovations not yet conceived of. To maintain America's competitive edge, we must accelerate our development and deployment of 5G.

Energy storage will be essential if the United States hopes to reliably provide the energy needed to power the technological landscape of today and tomorrow. Fossil fuels persist as an attractive fuel source due to their storage capacity at a volume 20 times higher than batteries and the increasing support of shale gas extraction infrastructure. Yet, the coal and gas-supported grid is foreseeably unreliable due to environmental instabilities and increasingly unattractive as international pressure to reduce our carbon footprint mounts. More funding for research and development of advanced materials can foster major technological breakthroughs in efficient fuel extraction, storage and deployment of sustainable energy solutions. Efforts such as the Joint Center for Energy Storage Research at Argonne National Laboratory are critical for identifying materials with the potential to revolutionize energy storage. Breakthroughs in this area will be necessary to fully reach the potential of electric cars and other modes of transportation.

We must capture the value of investments in research by supporting and accelerating the development of these and other advanced technologies in the United States. This will require increasing federal and state support for regional technology test beds, such as the Manufacturing USA institutes and Cyclotron Road at Lawrence Berkeley National Laboratory that incentivize technology transfer and partnerships between national laboratories, universities and businesses.

4. **Catalyzing the power and potential of the American worker** to thrive in an advanced manufacturing economy must be a fundamental priority as workforce demographics shift and the skills gap persists.

We need a workforce capable of succeeding in the hyper-connected, cross-disciplinary, advanced technology-based economy of the next decade. A number of steps are necessary to mitigating the challenge, including: growing the number and diversity of the STEM-educated workforce, establishing greater opportunities for experiential learning (e.g. co-ops and apprenticeships) and reforming rules to retain more skilled immigrants. Other critical steps include encouraging greater lifelong learning opportunities and re-establishing vocational education classes in K-12 that build a base for skilled trades.

5. **Securing U.S. energy critical infrastructure and next generation innovation is more important now than ever.** For this reason, the Council in 2018 launched a three-dialogue series on increasing the resilience of the nation's critical infrastructure, intellectual property and industrial operations against cyberattack. The final report, *Secure: Ensuring Resilience and Prosperity in a Digital Economy* puts forth a **National Agenda for Cybersecurity** with the power to secure and strengthen America's

resilience to the growing cyber threat while ensuring the nation remains competitive, productive and prosperous.

Of the 16 critical infrastructure identified by the Department of Homeland Security, the energy sector is disproportionately targeted by cyberattacks. At the same time, protecting our energy infrastructure from cyber threats is fundamental to U.S. economic and homeland security because of its crucial intersection with other critical infrastructures—from power and manufacturing to transportation and healthcare—that rely on energy to operate.

Building cybersecurity protections into new technology, requiring that all new technology applied to the electric grid meet widely-accepted security standards to build cyber resilience and protecting intellectual property on new energy innovations will be essential as the potential cost of cyberattacks escalates and the reliability of networks is increasingly called into question.

Another important measure in protecting America's critical technologies is requiring, under the new authorities of the Foreign Investment Risk Review Modernization Act (FIRRMA) in the National Defense Authorization Act for Fiscal Year 2019, that the Committee on Foreign Investment in the United States (CFIUS) conduct full reviews and regulatory approval for any foreign investment or ownership interest from hostile nations in American advanced startups, joint ventures or acquisitions. This applies not only to cybersecurity and energy but across the spectrum of technological innovation. These measures are necessary as countries like China target the U.S. start-up ecosystem in an effort to gain a competitive advantage.

Notwithstanding a currently robust economy, U.S. leadership in technology and long-term competitiveness are under threat. But the potential to succeed in the global economy is greater than ever before. This potential demands the urgent attention of our nation's leaders and a focused examination of our capabilities, investments and policies related to science, technology development and innovation. As the global landscape changes, the status quo is no longer sufficient if the United States hopes to maintain its leadership and capitalize on its bright energy future. A comprehensive strategy such as that put forward in *Accelerate* and similar reports by my colleagues on the panel will be essential if the U.S. hopes to achieve its full potential.

Conclusion

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

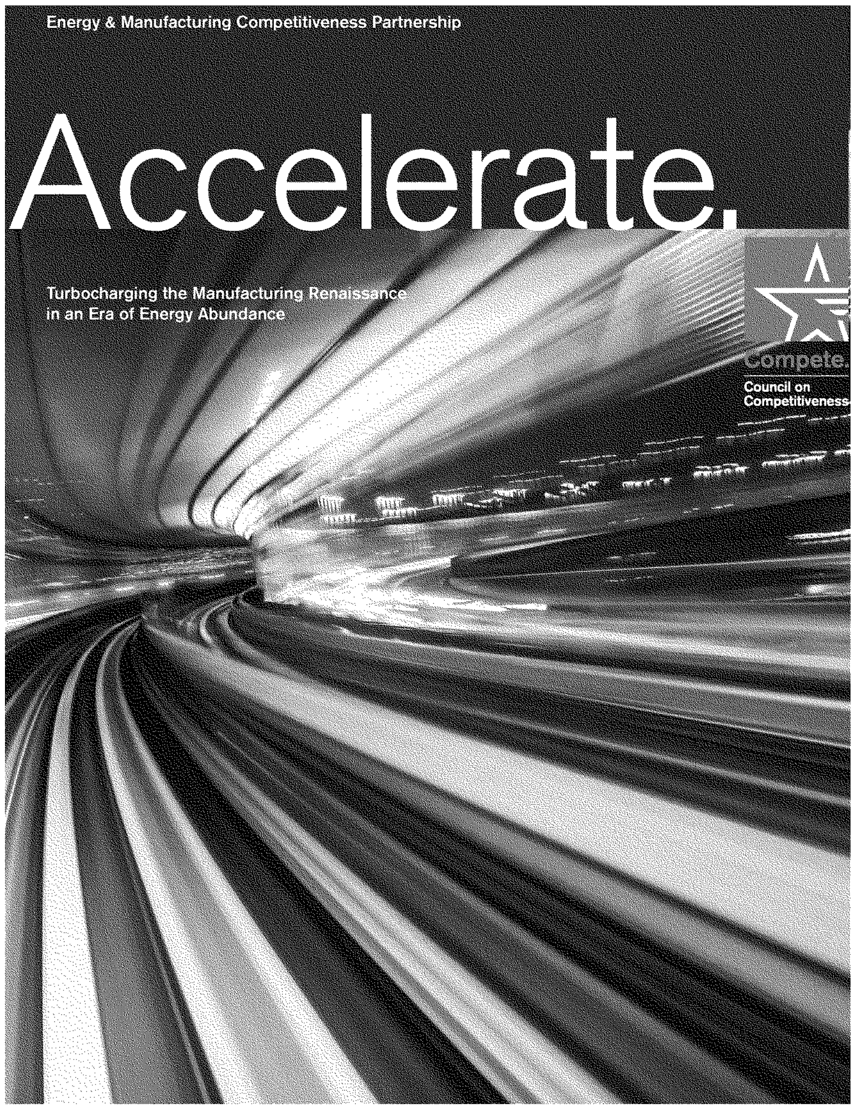
With these challenges in mind, the Council recently launched a **National Commission on Innovation & Competitiveness Frontiers** to double down on all efforts to optimize the nation for this new, unfolding innovation reality. Over the coming three years, the Commission will assemble top minds from industry, academia, labor and the national laboratories to:

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

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

More than any country in history, the United States has been the greatest driver and beneficiary of technology, innovation and a vibrant entrepreneurial spirit. We stand ready to work with you to set in place the policies needed to ignite a new era of competitive and sustainable growth and productivity.

Thank you.


Energy & Manufacturing Competitiveness Partnership
Accelerate.
Turbocharging the Manufacturing Renaissance
in an Era of Energy Abundance
Compete.
Council on
Competitiveness

Accelerate. Turbocharging the Manufacturing Renaissance in an Era of Energy Abundance

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Printed in the United States of America

Meeting the grand challenges—and even grander opportunities—of the 21st century demands an innovation-driven economy powered by a secure, sustainable, affordable energy portfolio and a robust, agile, advanced manufacturing sector.

America's ability to compete in and lead the global economy through this era of transformation hinges on bold, collaborative policy solutions leveraging America's total innovation ecosystem—industry, academia, labor and the national laboratories—at the heart of the nation's productivity and prosperity.

Table of Contents

Foreword

Following the success of two major initiatives exploring the U.S. economic opportunity in the energy and manufacturing spaces, the Executive Committee of the Council on Competitiveness (Council) recommended a new project be undertaken to merge these two policy streams and identify a set of recommendations that could ensure U.S. leadership founded on access to a diverse energy portfolio and the potential of an advanced manufacturing renaissance. Rising to the challenge were a tremendous set of leaders from among the Council membership who championed this effort, starting with the co-chairs: the Honorable Rebecca Blank, chancellor of the University of Wisconsin, Madison; Mr. Christopher Crane, president & CEO of Exelon Corporation; Mr. Jeff Fettig, chairman of Whirlpool Corporation; Dr. William H. Goldstein, director of Lawrence Livermore National Laboratory; and the Honorable Subra Suresh, former president of Carnegie Mellon University.

Consistent with the Council's mission to strengthen U.S. productivity, raise the standard of living for all Americans and expand global markets, its members and staff seek to constantly push the policy envelope, asking what's new on the horizon that holds the potential to either grow or inhibit U.S. prosperity. *Accelerate* captures the disruptions across the energy and manufacturing sectors and puts forth a road map for policymakers to follow that will allow the United States to lead, to capture value from new technologies and to prepare its citizens to prosper long term. The policy underpinnings of this effort will be a critical springboard for the launch of the National Commission on Innovation and Competitiveness Frontiers later this year.

Our thanks go out to the Council's members, its staff and the hundreds of experts who generously contributed their time to ensuring this report is both substantive and impactful.

Sincerely,

Samuel R. Allen
Chairman and Chief Executive Officer
Deere & Company

Mehmood Khan
Vice Chairman and Chief Scientific Officer
of Global Research and Development
PepsiCo, Inc.

Michael M. Crow
President
Arizona State University

Charles O. Holliday, Jr.
Chairman
Royal Dutch Shell plc

Deborah L. Wince-Smith
President & CEO
Council on Competitiveness

Letter from the Co-Chairs

In 2004, the Council sparked a national movement to "Innovate America," resulting in passage of the America COMPETES Act and a renewed commitment to U.S. creativity, entrepreneurship and global leadership in emerging technologies. Five years later, we declared "Energy is Everything" and embraced a broad portfolio of energy resources to power America's innovation engine. In 2012, the Council galvanized an American manufacturing movement centered around the nascent advanced manufacturing renaissance and its critical role to the vitality of the entire U.S. economy.

Today, America has entered a new frontier shaped by the tremendous opportunity of low-cost domestic energy abundance, the proliferation of game-changing disruptive technologies and the availability of powerful tools from supercomputers to 3D printers to futuristic biomanufacturing processes. And the Council is leading once again.

In *Accelerate*, we are pleased to share with you the critical findings and recommendations of the Energy and Manufacturing Competitiveness Partnership (EMCP). Led by a C-suite Steering Committee comprising leaders from industry, academia, labor and the national laboratories, the EMCP brought together more than 300 experts and practitioners to assess the economic opportunity at the nexus of energy and manufacturing and define a national policy agenda to catalyze the U.S. manufacturing renaissance. Through the leadership of several Steering Committee members, the EMCP approached America's diverse industrial landscape not as a monolith, but as a network of distinct but interdependent sectors, each with its own challenges and opportunities.

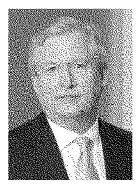
Through six diverse regional sector studies encompassing bioscience, advanced materials, water, agriculture, energy and aerospace, the EMCP explored how cross-cutting factors play out within each sector, identified discrete factors shaping each sector and assessed common threads that span the economy. One such thread that wound itself inextricably throughout every sector was the promise and pitfall of cybersecurity. At the direction of the Steering Committee a related, but separate policy effort was undertaken to develop a national agenda for cybersecurity and a companion report accompanies this one.

Importantly, *Accelerate* presents a road map of concrete actions from investments in research to regulatory experimentation to educational innovation. And it calls upon all stakeholders in the economy to engage and leverage the seminal opportunity the current landscape has created and catalyze a new wave of productivity and prosperity.

Looking forward, the work of the EMCP provides an important foundation upon which the Council's National Commission on Innovation & Competitiveness Frontiers can build. Formally launching later this year, the Commission will continue the Council's thought leadership, pushing the policy envelope to capture the economic potential of emerging technologies and America's ever evolving innovation ecosystem.

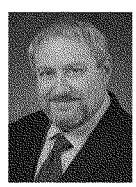
We thank the private and public sector leaders and experts for their support and contributions and look forward to working together to build a more prosperous, productive and secure America.

Sincerely,



Christopher Crane
President & CEO
Exelon Corporation

Rebecca Blank
Chancellor
University of Wisconsin–Madison



William H. Goldstein
Director
Lawrence Livermore National Laboratory

Executive Summary

For more than two centuries, American industry has harnessed the nation's abundance of natural resources, energy, talent and ingenuity to power and unleash the most productive economy in the world.

Dramatic shifts spurred by globalization, recession, regulatory and tax trends, ascendant and increasingly advanced industrial activity across Europe and Asia and accelerating changes in consumer demand have buffeted America's industrial and manufacturing enterprises, threatening America's place as a global superpower. Yet today, America finds itself facing a new, promising frontier shaped by two powerful transformations working in tandem:

- The generational re-emergence of advanced and highly productive manufacturing capacity in the United States; and
- The increasing abundance of innovative, sustainable, affordable and domestically-sourced energy.

To capitalize on this convergence, the Council on Competitiveness (Council) launched the Energy and Manufacturing Competitiveness Partnership (EMCP) in 2015, which leveraged more than a decade of leadership in the energy and manufacturing fields that began with the seminal National Innovation Initiative (NII) in 2003 and continued most recently with the Energy Security, Innovation and Sustainability Initiative (ESIS, 2007–2009), the U.S. Manufacturing Competitiveness Initiative (USMCI, 2010–2011) and the American Energy and Manufacturing Competitiveness Partnership (2012–2016). The EMCP, a C-suite-directed initiative, focused on the shifting global energy and manufacturing landscape and how energy transformation and demand are shaping industries critical to America's prosperity and security.

Over a span of three years, the Council executed an ambitious roadmap to focus national attention on the intersection of the energy and manufacturing transformations. Recognizing the tremendous innovation and changing landscape across the manufacturing sector, from 3D printing to the proliferation of sensing devices and the use of advanced modeling and simulation tools, the EMCP was designed to approach the country's diverse industrial landscape as a network of distinct but interdependent productive sectors, each with its own challenges and opportunities. Through a series of sector studies hosted around the nation by members of the Steering Committee, the EMCP identified the salient questions and challenges facing the energy-manufacturing nexus within key sectors of the economy. Seeking input from leaders throughout the private sector, academia, the research and scientific community, NGOs and government, each of the six sector studies looked at how decision-makers can bolster the critical pillars of competitiveness-technology, talent, investment and infrastructure.

The picture painted by these sector studies is, from one perspective, bleak.

- The United States is plagued by outdated regulatory and physical infrastructure that is failing to keep pace with innovation in sectors from materials to aerospace and beyond.

- The absence of a coordinated, defined research agenda to guide insufficiently-funded research and development is limiting the potential for advancement in key sectors such as bioscience.
- Science has a perception problem that can only be combatted through increased scientific literacy.
- The skills gap is growing, and will continue to get worse as workforce demographics shift.
- And, while all this is happening at home in the United States, global competition is ramping up as countries around the world realize the advantages of investing in a strong innovation ecosystem.

Yet, the United States is not without its strengths. American innovators—icons of industry, brilliant scientists and engineers, and everyday geniuses—continue the nation's 150-year legacy of reshaping entire industries, the marketplace and the world with breakthrough technologies, products and services. Hundreds of renowned research institutions and national laboratories keep the United States at the forefront of knowledge creation and on the cutting edge of game-changing technologies. The nation's culture of entrepreneurship, risk-taking and creativity—stoked by venture capital—is unmatched around the globe. Additionally, America's transition from energy dependence to energy abundance is of unparalleled promise.

Wise policies and practices, in many cases, could unleash these American strengths, boost manufacturing engines and raise technology commercialization to new heights, driving U.S. economic growth and job creation. Developing next-generation physical and regulatory infrastructure to support the nation's advanced energy and manufacturing enterprise will build the foundation upon which America's economy can thrive and compete. Fueling the innovation and production economy from idea to implementation will allow for increased industrial productivity as the United States reaffirms its leadership in new knowledge creation and its end-use application. Moreover, catalyzing the power and potential of the American worker to thrive in an advanced manufacturing economy will enable the advanced technology-based economy of the next decade to provide higher-paying jobs for American families.

> "The United States stands at an economic inflection point where we can either seize the opportunity in front of us or watch others take the lead in critical sectors from AI to big data to additive manufacturing."
>
> **The Honorable Deborah L. Wince-Smith**
> President & CEO
> Council on Competitiveness

These key challenges, opportunities and recommendations discussed throughout sector studies on water and manufacturing, advanced materials, bioscience, agricultural and consumer water use, energy and aerospace—along with findings from a three-dialogue series on American cybersecurity—underpin this report and are the foundation for the Council's call to action.

The recommendations in this report—and the over ten years of work they encompass—have the power to turbocharge America's manufacturing capabilities, improve America's competitiveness and unleash a new wave of productivity, prosperity and resilience for all Americans.

Call to Action

Building upon more than a decade of work on energy and manufacturing policy as key enablers of U.S. productivity, prosperity and security, the Council on Competitiveness in 2015 launched the Energy and Manufacturing Competitiveness Partnership (EMCP). Led by a C-suite group from industry, academia, labor and the national laboratories, the EMCP approached America's diverse industrial landscape not as a monolith, but as a network of distinct yet interdependent sectors, each with its own challenges and opportunities.

Through six sector studies, the EMCP explored how cross-cutting factors play out within each sector, identified discrete factors shaping each sector and assessed common challenges and opportunities that span across the economy—most prominently, cybersecurity, which was explored in-depth through three regional dialogues across the country.

Based on the Council's decade-long leadership and the learnings of the EMCP, this call to action constitutes a national policy agenda to drive America's future energy and manufacturing competitiveness. If implemented, this agenda would turbocharge the U.S. manufacturing renaissance and drive economic prosperity for the nation and for all Americans.

Develop next generation physical and regulatory infrastructure to support the nation's advanced energy and manufacturing enterprise.

1. Create a modern, enabling regulatory infrastructure to keep pace with innovation and spur economic growth.

1.1. Encourage state and local governments to continue experimenting with new regulatory frameworks to test and evaluate the viability of disruptive technologies, from autonomous vehicles to next-generation nuclear power.

1.2. Review federal regulations to avoid redundancy and ensure states and other entities have the flexibility to propose and implement innovative regulatory models and explore new technologies needed to enable the advanced energy and manufacturing enterprise.

1.3. Make permanent Executive Order 13771 requiring that, subject to a rigorous cost/benefit analysis, two regulations be eliminated before a new regulation can be promulgated.

2. Break the cycle of incremental infrastructure improvements to spur creative and forward-looking approaches to the movement of goods, services and people.

2.1. Substantially increase federal and state investment in U.S. infrastructure to repair and modernize the roads, airports, rails and water systems upon which the economy relies.

2.2. Dedicate a percentage of federal infrastructure funding to leapfrog demonstration projects that leverage next-generation technologies, obviating the "patch and repair" cycle of current infrastructure spending.

2.3. Create partnerships between industry and local governments to develop and propose innovative infrastructure models that support next generation energy and transportation initiatives.

3. Bring the United States energy market infrastructure and regulatory ecosystem into the 21st century.

3.1. Secure U.S. leadership and investment in nuclear technology by leveling the regulatory playing field, ensuring adequate funding for basic nuclear research and increasing support for nuclear engineering degree programs.

3.2. Modernize the electric grid by reforming state regulations to allow utilities to depreciate outdated equipment more quickly.

3.3. Catalyze innovation in the utility sector by allowing utilities to recoup a percentage of investments in R&D through rate increases.

Fuel the innovation and production economy from idea to implementation.

4. Reaffirm U.S. leadership in new knowledge creation and better align research efforts to meet the grand challenges facing the nation and the world.

4.1. Increase federal investment in research and development across all agencies at a consistent, predictable rate with an overall target of one percent of GDP.

4.2. Under the direction of the Science Advisor to the President, align the national research agenda with industrial grand challenges and prioritize disruptive technologies with high potential for economic and societal impact.

5. Capture the value of investments in research by supporting and accelerating the development of advanced technologies in the United States.

5.1. Increase federal and state support for regional technology test beds, such as the Manufacturing USA institutes.

5.2. Incentivize technology transfer and partnerships between national laboratories, universities and businesses by streamlining intellectual property agreements, considering industry collaboration as part of promotion and tenure decisions, and clarifying that industrial partnerships with national labs are consistent with their mission.

5.3 Close the valley of death in private sector financing to enable startup to scale-up.

6. Leverage and secure the Internet of Things to drive industrial productivity.

6.1. Incentivize the use of sensors and monitoring equipment for energy and water usage in public and private sector facilities at the state and local level through tax credits and other mechanisms.

6.2. Encourage greater uptake and use of standardized criteria, such as the UL Cybersecurity Assurance Program to increase supply chain security.

6.3. Require that all new technology applied to the electric grid meet widely-accepted security standards to build cyber resilience.

7. Extrapolate insight and value from the data tsunami.

7.1. Create a federal verification system for crowdsourced data to enhance the validity and usefulness of knowledge databases across multiple sectors.

Catalyze the power and potential of the American worker to thrive in an advanced manufacturing economy.

8. Develop a workforce capable of succeeding in the hyper-connected, cross-disciplinary, advanced technology-based economy of the next decade.

8.1. Integrate technical training into K-12 education, including industrial arts programming, to build a better base of technological understanding by all Americans.

8.2. Strengthen the lifetime linkages between universities and graduates to enable life-long learning opportunities.

8.3. Develop a multi-stakeholder public awareness campaign to increase scientific literacy.

9. Facilitate greater collaboration, interaction and exchange between industry and secondary and higher education institutions to spur partnerships and highlight workforce opportunities.

9.1. Reduce state and education institutional barriers to allow more practitioners into the classroom and to inspire the next generation of advanced manufacturing workers.

9.2. Encourage industry partnerships with educational institutions to enable practitioners to engage with students in K-12 and higher education.

10. Implement the Council on Competitiveness National Cyber Agenda

10.1. See appendix A

Setting the Stage

Throughout history, the great leaps in productivity and prosperity at the heart of national competitiveness have come through the emergence, adaptation and adoption of new processes, materials and technologies. Innovation—the intersection of invention and insight, leading to the creation of social and economic value—is the life-blood of the global economy and the catalyst behind these trends. Innovation is deeply embedded in America's DNA. From birth, the United States has been fundamentally about exploration, opportunity and discovery; about new beginnings; about setting out for the frontier.

When the Council began to explore the energy and manufacturing nexus back in 2007 through its Energy Security, Innovation and Sustainability Initiative, the world looked very different. Energy consumption was rising exponentially, driven by worldwide population growth, swiftly developing economies, improving global living standards and the burgeoning use of ever more energy-dependent technologies. America's growing dependence on imports to meet energy needs had become a major factor in the trade deficit, accounting for more than 45 percent, while dependence on foreign oil translated into an outflow of $439 billion dollars annually. At the same time, the growing dependence on foreign sources of natural gas and petroleum was posing a serious challenge to U.S. national and economic security, and private sector leaders were beginning to embrace the imperative for sustainability and transition to a low-carbon world.

Today, America finds itself facing a new, promising frontier shaped by two powerful transformations working in tandem:

"Lower cost, clean and abundant energy from multiple sources have enabled the United States to recapture momentum in the manufacturing sector. We must make sure policy keeps pace to allow the U.S. to capture maximum value from this new reality."

Mr. Christopher Crane
President & CEO
Exelon Corporation

- The generational re-emergence of advanced and highly productive manufacturing capacity in the United States; and
- The increasing abundance of innovative, sustainable, affordable and domestically-sourced energy.

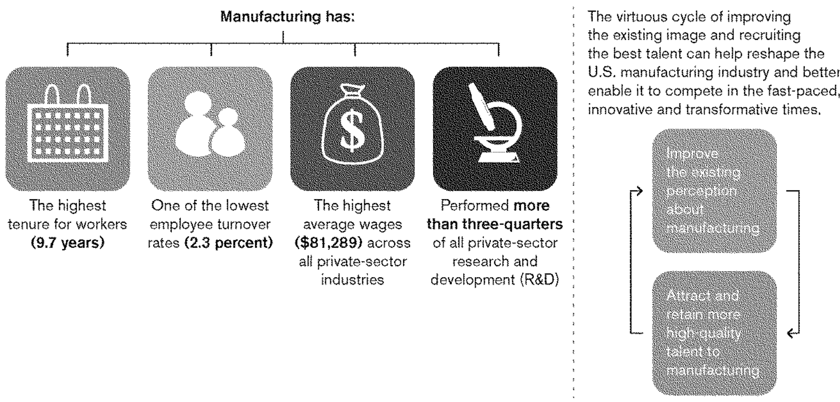
The ability to capitalize on these transformational shifts will be paramount for American competitiveness, now and in the decades to come.

The Manufacturing Engine

The U.S. manufacturing sector remains the nation's primary driver of research and development, the largest employer of science and engineering graduates in the country and a central catalyst for technology innovation throughout the economy. Manufacturing remains critical to the American economic prosperity and the future of U.S. global competitiveness. As a sector, manufacturing con-

Figure 1. Addressing the Manufacturing Skills Gap: Sharing the Good News to Attract and Retain Top Talent

Source: Deloitte and the Manufacturing Institute. *A Look Ahead: How Modern Manufacturers Can Create Positive Perceptions with the U.S. Public.*



tributes approximately 11.6 percent of U.S. GDP,[1] and employs more than 12 million people directly in addition to supporting 5.4 million more jobs indirectly.[2] As Figure 1 highlights and the Council's *Make* report made clear, manufacturing jobs are no longer dirty, dumb, dangerous and disappearing, but are high-tech, high-paying and highly sought after positions at the forefront of the U.S. manufacturing resurgence. The effect of this sector's job creation is reflected in the decreasing unemployment rate in the United States over the last several years. Lowering the 2010 unemployment rate from 8.6 percent to 5 percent would have required the creation of 21 million jobs. Today, the U.S. unemployment rate hovers around 4 percent—in large part due to the growth of the manufacturing sector. In addition to its tremendous job creation power, the manufacturing sector adds $1.34 in output from other sectors for every dollar in final sales of manufactured products—the largest multiplier of any sector.[3]

1 Gross Domestic Product by Industry: First Quarter 2018, Bureau of Labor Statistics and Bureau of Economic Analysis.

2 Bureau of Labor Statistics, Employment by Major Industry Sector, October, 2017.

3 Facts About Manufacturing, Manufacturing Institute, MAPI, National Association of Manufacturers.

A Transformation in Production

Today, U.S. manufacturing stands at a critical juncture. A deep and disruptive transition in U.S. manufacturing has taken place since 2000, with more than 60,000 American factories, companies and almost 5 million manufacturing jobs lost from 2001 to 2014.[4]

However, particularly since the Great Recession, the pendulum has started to swing back in the direction of the United States. Wages overseas are rising; for example, labor costs in China more than quadrupled from 2004 to 2016.[5] The shale oil and gas boom has given many American producers a critical cost advantage. Meanwhile, according to the *Global Manufacturing Competitiveness Index*, a joint effort with Deloitte, industry executives now rank the U.S. at No. 2 globally for manufacturing competitiveness, only behind China, and trending up during the past decade.

At the same time, U.S. manufacturing is in the midst of an ever-evolving digital disruption. The physical and digital worlds are converging across numerous dimensions through sensors, networks, additive manufacturing and a data tsunami. Sensing and computing across natural, built and social environments are generating data at unprecedented scale, complexity and speed.

In production alone, companies will have the ability to better understand the operation of every machine and device, the cut of every blade, every movement of material and the consumption of energy minute by minute. Virtual design through modeling and simulation using advanced computing will accelerate innovation and product development, while dramatically reducing costs and risks.

Autonomous systems are advancing rapidly. Applications such as drones and driverless vehicles are being applied in factories to detect and react to problems, enabling the adaptation of machinery and systems to changing conditions. This is a productivity revolution in the making. Investments in smart manufacturing could generate cost savings and productivity gains worth $10-$15 trillion in global GDP over the next 15 years—that is almost as big as the U.S. economy.

Decoupling Energy from Growth

Interestingly, American economic growth is picking up steam without a parallel increase in energy consumption. Since 2008, primary energy usage has shrunk 1.7 percent, even as GDP has accelerated by 15.3 percent (see Figure 2).[6] This occurrence of economic growth without a corresponding increase in energy consumption is consistent with a long-term decoupling trend the United States has seen during the past 20+ years. From the years 1950-1990, demand for electricity increased annually at an average rate of 5.9 percent. However, this pattern took a dramatic turn from 1990 through 2007, when the demand for electricity dropped to 1.9 percent growth per year. Since 2007, however, the United States has seen a contraction in electricity demand per year by an average rate of 0.2 percent. And in 2017, energy usage shrunk 1.7 percent while U.S. GDP increased by 15.3 percent.[7]

4 *Statistics of U.S. Businesses*, The United States Census Bureau, 2015 (accessed September 2018).

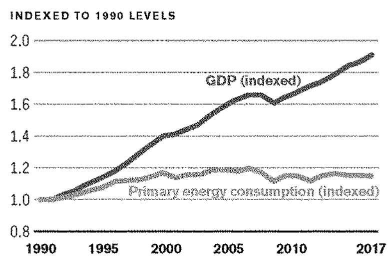
5 Bank of America Merryl Lynch Global Research, January 14, 2016.

6 *2018 Sustainable Energy in America Factbook*, Bloomberg, 2018.

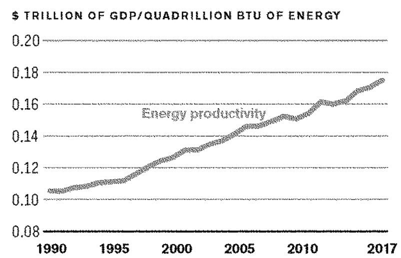
7 ibid.

Figure 2.
Source: Bureau of Economic Analysis, EIA, Lawrence Berkeley National Laboratory, BNEF.

U.S. GDP and Primary Energy Consumption



U.S. Energy Productivity



This decoupling of economic growth from energy use can be attributed to a variety of factors, including an increase in energy productivity—doing more with less—generating greater economic well-being for the amount of energy used, and improving living standards and quality of life.[8] In response to a presidential call to action and in recognition of the importance of energy productivity to American competitiveness, the Council in 2014 partnered with the U.S. Department of Energy and the Alliance to Save Energy to launch a series of public dialogues and executive roundtables to raise awareness, galvanize support and develop the strategies necessary to double the United States' energy productivity by 2030. The outcome, *Accelerate Energy Productivity 2030: A Strategic Roadmap for American Energy Innovation, Economic Growth and Competitiveness*, put forth a plan to achieve significant growth in energy productivity—which, because of this and related work is largely being realized today.

Another factor that has contributed to the weakened correlation between economic growth and energy usage is the increase in energy-efficient technologies, processes and practices. This transformation has been driven in large part by the availability of low-cost natural gas, which is three times more efficient than electricity in providing energy for end-use applications and has increased exponentially as a share of total energy used in U.S. manufacturing. In fact, natural gas comprised nearly 40 percent of all energy consumed by the industrial sector in 2015—up almost 10 percent from 2006.[9]

8 *Accelerate Energy Productivity 2030*, U.S. Department of Energy, Council on Competitiveness and the Alliance ot Save Energy. September 16, 2015.

9 *U.S. Primary Energy Consumption by Source and Sector*, U.S. Energy Information Administration, 2017.

A Changing Energy Mix

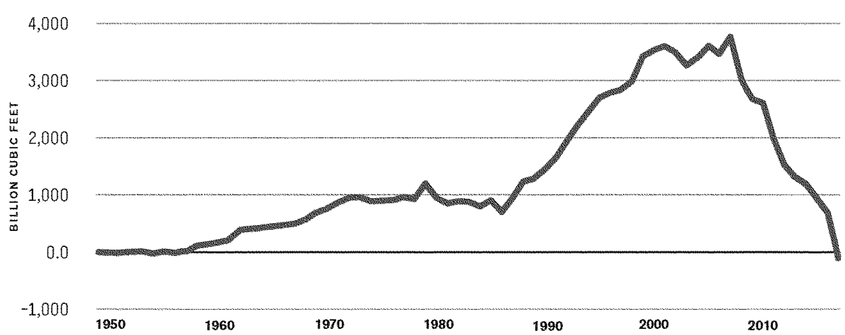
Historically, industrial power prices in the United States have been among the most affordable in the world—second among the G7 nations only to Canada.[10] Even as exchange rates have brought down the dollar cost of energy for consumers in China, Japan and Mexico, U.S. energy costs remain competitive, with prices nearly half as low as Japan and Germany. And as the energy mix in the United States continues to shift away from its former reliance on fossil fuels, corporations and state and federal governments are increasingly driving the energy transformation, demanding cleaner energy and seeking to capture gains from energy efficiency.

Meanwhile, the legacy coal and gas-supported electric grid is under tremendous strain due to increasingly diverse energy sources coupled with environmental instabilities and extreme weather phenomena and volatility. American advanced manufacturing requires a reliable, resilient, diverse and flexible energy mix that encourages efficiency and supports the opportunity for investment in new technologies that benefit Americans, underpin national security needs and convey competitive global advantage to U.S. businesses.

From Scarcity to Abundance

Concurrent with the divergence between energy use and economic growth, the United States solidified its role as a global exporter of liquefied natural gas in 2017 when, for the first time, it became a net exporter—rather than importer (see Figure 3)—of natural gas in each month of the year.[11] Enabled largely by a 7.2 percent decline in the amount of

Figure 3. Natural Gas Imports
Source: U.S. Energy Information Administration



10 *2018 Sustainable Energy in America Factbook*, Bloomberg, 2018.

11 ibid.

natural gas used to generate gas-fired power, domestic gas demand decreased by 2.8 percent year-on-year. The growth in foreign demand for liquified natural gas occurred at the same time as this growth in efficiency, allowing the United States to become a net exporter of natural gas. The United States currently exports liquified natural gas to 25 countries, with its primary importers being Mexico, South Korea, China and Japan.[12]

But natural gas is just one piece of America's energy puzzle. Nuclear power, for example, is an important part of the energy sector and provides another clean, viable energy alternative. In the past thirty years, operating capacity in nuclear power plants increased from 60 percent to over 90 percent.[13] Yet even with this marked increase, regulatory barriers hinder the nuclear industry from reaching its full potential. A recent study by the Nuclear Energy Institute (NEI) found that oil, gas, hydro, solar, wind and biomass received more than 90 percent of all economic incentives–tax policies, regulation, research and development, market activity, government services and disbursements–provided to the energy industry since 1950.[14] And while the government has supported nuclear energy development through research and development programs, over the last twenty years, federal spending on research and development for coal and renewables has exceeded funding allocated to the nuclear industry. Throughout a recent six year period alone (2011–2016), renewable energy obtained more than 27 times more federal aid in incentives than nuclear energy. Maintaining America's leadership position in nuclear technology and innovation is essential for economic competitiveness in the global energy market.

The stage is set for the United States to leverage these transformations in energy and manufacturing through a comprehensive public and private sector strategy that capitalizes on the nation's unparalleled competitive assets. An America that operates in a 21st century infrastructure–with a high-skilled workforce and access to the capital needed to grow and scale entrepreneurial businesses–has the potential become the catalyst for a new wave of productivity and prosperity and to usher in a low-carbon world.

12 *2018 Sustainable Energy in America Factbook*, Bloomberg, 2018.

13 *Nuclear Power in the USA*, World Nuclear Association, August 4, 2017.

14 *Analysis of U.S. Energy Incentives–1950-2016*, Nuclear Energy Institute, 2017.

A Decade of Leadership in Energy and Manufacturing

The EMCP builds upon and merges more than a decade of leadership in the Council's energy and manufacturing work streams, including most recently the Energy Security, Innovation and Sustainability Initiative (ESIS, 2007–2009), the U.S. Manufacturing Competitiveness Initiative (USMCI, 2010–2011) and the American Energy and Manufacturing Competitiveness Partnership (2012–2016).

Each of these initiatives sought to navigate the ever-evolving currents of national and global economies punctuated by technological, demographic and financial disruptions. In 2008, the goal was energy security rather than independence, interest rates were headed to near zero and the potential economic impact from technologies like artificial intelligence were more theoretical than quantifiable. Today, the United States is an energy exporter, the Federal Reserve is raising rates in the face of full employment and rising inflation and AI is projected to be a trillion-dollar industry. The Council's policy efforts have adapted, as well.

Energy Security, Innovation & Sustainability Initiative

In July 2007, the Council launched the ESIS Initiative in recognition of the critical linkages among these three issues and their profound impact on future U.S. productivity, standard of living and global market access. The genesis for the initiative was the Council's 2004 groundbreaking report of the National Innovation Initiative (NII), *Innovate America*. The NII recognized energy security as a significant challenge on the horizon—one that, if left unaddressed, could undermine America's competitiveness in the years ahead (see Appendix B).

Drawing upon more than a year's work of inquiry and real-time research and analysis, in anticipation of the 2008 change in administration, the Council issued *Prioritize: A 100-Day Energy Action Plan for the 44th President of the United States* in September 2008. The plan identified six "pillars" as integral to U.S. energy transformation and as top priorities for presidential action upon taking office:

- Setting the global bar for energy efficiency;
- Assuring access to clean and competitive energy;
- Jumpstarting energy infrastructure investments;
- Spawning technological breakthroughs and entrepreneurship;
- Mobilizing a world-class energy workforce; and
- Clearing obstacles to a national transmission superhighway.

At that time, the Council stressed that the action plan recommended in *Prioritize* marked the beginning, not the end, of a concerted commitment to ensuring the United States achieves energy security in a sustainable manner, while driving the competitiveness of its workers, industries and economy.

Following *Prioritize*, the Council released *Drive: A Comprehensive Roadmap to Achieve Energy Security, Sustainability and Competitiveness* at the 2009 National Energy Summit in Washington, D.C. *Drive* built upon the energy action plan in *Prioritize* and set forth the next set of integrated building blocks for America's energy transformation, sustainability and competitiveness in a low-carbon world (see Figure 4). The recommendations presented in *Drive* sought to unleash a new era of American innovation, create new industries, revitalize and re-build manufacturing jobs across the nation, keep and grow high-skilled jobs for this generation and the next, and accelerate economic prosperity for all Americans.

Figure 4. *Prioritize* and *Drive* Recommendations

Prioritize Pillar	*Drive* Recommendation
1. Setting the Global Bar for Energy Efficiency	Reward Efficiency
2. Assuring Access to Clean and Competitive Energy	Use It All and Price It Right
3. Jumpstarting Energy Infrastructure and Manufacturing Investments	Capitalize Growth and Make it Here
4. National Transmission Superhighway and Smart Grid	Build It Fast and Smart
5. Spawning Technological Breakthroughs and Entrepreneurship	Discover the Future and Break the Technology Barriers
6. Mobilizing a World-Class Energy Workforce	Bridge the Skills Gap and Train the Talent

Prioritize and *Drive* laid out the prerequisites that must be met to be successful in developing and deploying large-scale sustainable energy solutions worldwide. Additionally, *Drive* set forth, in its comprehensive roadmap building upon the six pillars, specific recommendations that, if implemented, would achieve the trifecta of simultaneously promoting America's economic competitiveness, enhancing national security and improving the global environment (see Appendix C).

U.S. Manufacturing Competitiveness Initiative
Building on the heritage of the NII, the Council also identified manufacturing as an issue critical to the preservation and growth of U.S. innovation capacity.

In June 2010, the Council launched the U.S. Manufacturing Competitiveness Initiative (USMCI) to begin a new dialogue on the policies and practices necessary to ensure the long-term success of American manufacturing. Over two years, this initiative identified critical research, innovation and policy trends contributing to the re-emergence of America's high-value, advanced and productive domestic manufacturing sector.

The USMCI culminated in the report *Make: An American Manufacturing Movement* that identifies key trends and offers solutions that enable manufacturing to strengthen America's competitiveness, stan-

National Innovation Initiative

The National Innovation Initiative (NII) began in 2003 as a multi-year effort engaging hundreds of leaders across the country and from all walks of life to optimize the entirety of American society for a future in which innovation is the single most important factor in shaping prosperity.

In 2004, more than 500 leaders from around the world attended the National Innovation Summit in Washington, D.C., where the Council released the landmark report, *Innovate America: Thriving in a World of Challenge and Change.*

Innovate America defined innovation as the intersection of invention and insight, leading to the creation of social and economic value, and called for America to "innovate or abdicate." The ground-breaking agenda put forth in the report includes more than 60 detailed recommendations grouped under the innovation platforms: talent, investment and infrastructure.

In August 2007, President George W. Bush signed the America COMPETES Act into law, which finds its roots in *Innovate America* and in the work of the Council's National Innovation Initiative.

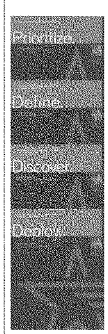
Along with the America COMPETES Act, the NII would underpin the next 15 years of Council policy leadership and forms the base upon which this report is built.

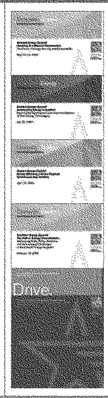
Talent	Investment	Infrastructure
Build a National Innovation Education Strategy for a diverse, innovative and technically-trained workforce	Revitalize Frontier and Multidisciplinary Research	Create National Consensus for Innovation Growth Strategies
Catalyze the Next Generation of American Innovators	Energize the Entrepreneurial Economy	Create a 21st Century Intellectual Property Regime
Empower Workers to Succeed in the Global Economy	Reinforce Risk-Taking and Long-Term Investment	Strengthen America's Manufacturing Capacity
		Build 21st Century Innovation Infrastructures—the health care test bed

COUNCIL CHAIRMEN
Mr. F. Duane Ackerman, Chairman & CEO, Bell South
Mr. Charles O. Holliday, Jr., Chairman & CEO, DuPont

2003 2004 2005 2006 2007 2008 2009 2010

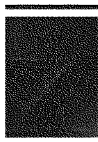
The Energy Security, Innovation & Sustainability initiative, led by Mr. James Owens, former Chairman and CEO of Caterpillar, Inc.; Mr. D. Michael Langford, National President of the Utility Workers Union of America; and the Honorable Shirley Ann Jackson, President of Rensselaer Polytechnic Institute, united industry, labor and academia to present a blueprint for America's energy future to the private sector and to the incoming president ahead of the 2008 election.





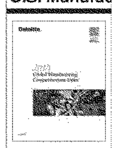
Energy Security, Innovation & Sustainability initiative

National Innovation Initiative



The National Innovation Initiative, co-chaired by Mr. Samuel J. Palmisano, Chairman and Chief Executive Officer, IBM Corporation and Dr. G. Wayne Clough, President, Georgia Institute of Technology, presented a National Innovation Agenda that has been put to action in many ways and underpins the America COMPETES Act signed into law by President George W. Bush in 2007.

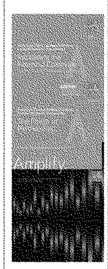
U.S. Manufac

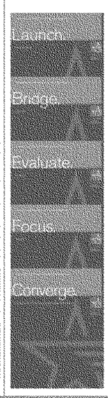


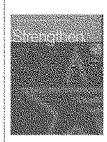
Mr. Samuel R. Allen, Chairman & CEO, Deere & Company

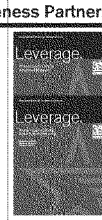
2011	2012	2013	2014	2015	2016	2017	2018

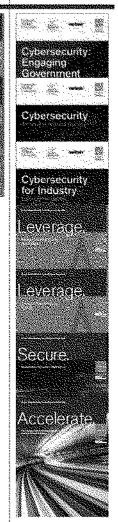
Energy & Manufacturing Competitiveness Partnership





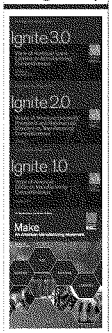


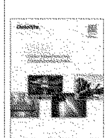




American Energy & Manufacturing Competitiveness Partnership

turing Competitiveness Initiative





At the vanguard of the movement to build an American manufacturing renaissance, the U.S. Manufacturing Competitiveness Initiative—led by Dr. Susan Hockfield, former President of MIT; Dr. George Miller, former Director of Lawrence Livermore National Laboratory; and Mr. James Quigley, former CEO of Deloitte LLP, established an ambitious agenda to bolster America's manufacturing sector—an agenda which continues to inform public policy in and beyond Washington.

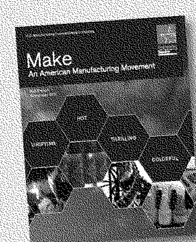
dard of living and national security. *Make* put forth a comprehensive agenda to solve five critical challenges facing American manufacturing:

- Fueling the innovation and production economy from start-up to scale-up;
- Expanding U.S. exports, reducing the trade deficit, increasing market access and responding to foreign governments protecting domestic producers;
- Harnessing the power and potential of American talent to win the future skills race;
- Achieving next-generation productivity through smart innovation and manufacturing; and
- Creating competitive advantage through next generation supply networks and advanced logistics and infrastructure.

As a part of the USMCI effort, the Council, in partnership with Deloitte, created the *Global Manufacturing Competitiveness Index (GMCI)*, which reflects the views of more than 400 senior manufacturing executives worldwide. The GMCI, conducted first in 2010 and then again in 2013 and 2016, found that in order to succeed in the rapidly evolving global manufacturing landscape, companies will need to embrace a targeted approach to some of the key elements of manufacturing competitiveness, including: ensuring talent is the top priority; embracing

Call to Action: Five Challenges and Solutions to Make an American Manufacturing Movement

See full text in Appedix D, page 76.



1. **Challenge:** Fueling the innovation and production economy from start-up to scale-up

   Solution: Enact fiscal reform, transform tax laws and reduce regulatory and other structural costs and create jobs.

2. **Challenge:** Expanding U.S. exports, reducing the trade deficit, increasing market access and responding to foreign governments protecting domestic producers.

   Solution: Utilize multilateral fora; forge new agreements; and advance IP protection, standards and export control regimes to grow high-value investment and increase exports.

3. **Challenge:** Harnessing the power and potential of American talent to win the future skills race.

   Solution: Prepare the next generation of innovators, researchers and skilled workers.

4. **Challenge:** Achieving next-generation productivity through smart innovation and manufacturing.

   Solution: Create national advanced manufacturing clusters, networks and partnerships; prioritize R&D investments; deploy new tools, technologies and facilities; and accelerate commercialization of novel products and services.

5. **Challenge:** Creating competitive advantage through next generation supply networks and advanced logistics and infrastructure.

   Solution: Develop and deploy smart, sustainable and resilient energy, transportation, production and cyber infrastructures.

advanced technologies to drive competitive edge; leveraging strengths of ecosystem partnerships beyond traditional boundaries; developing a balanced approach across the global enterprise; and cultivating smart, strategic public-private partnerships.

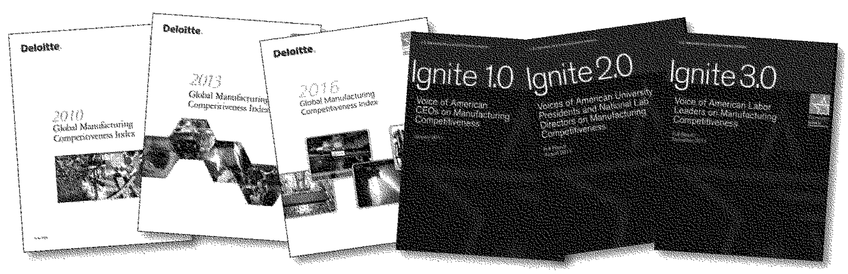
Most notably, in 2016, respondents predicted for the first time that the United States will take the top spot in the Global Manufacturing Competitive Index (GMCI) by 2020 while China, the manufacturing competitiveness leader in 2010, 2013, and 2016, falls to second place as it transitions toward higher-value manufacturing and adjusts to rising material and labor costs. This would have significant competitiveness implications for the United States and the world.

The *Ignite 1.0-3.0* report series, another collaboration with Deloitte, succeeded the initial GMCI. The multi-part, interview-driven project collected insights from CEOs, university presidents, national laboratory directors and labor leaders, and captured several areas in which these diverse perspectives converge on actions needed to invigorate American manufacturing. The series illuminated several key findings that have informed the Council's work to date, including: the criticality of infrastructure development to job creation and competitiveness; the demand for government policies to address uncertainty and encourage business; the importance of manufacturing to America's ability to compete in the global marketplace; and the role of superior talent as key to America's competitiveness.

American Energy & Manufacturing Competitiveness Partnership

Prior to 2009, the tone of the nation's energy conversation was centered on methods for addressing long-standing energy security challenges and scarcity. By 2013, the conversation had shifted and began to focus on seizing emerging energy growth opportunities to transform America's industrial base and job creation outlook—centering on energy abundance and strength.

In this context, the Council and the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy launched the American Energy & Manu-



Foundation of AEMC Partnership

REPORTS

184 reviewed

28 selected for in-depth analysis

180 recommendations

26 policy categories analyzed

PUBLIC-PRIVATE PARTNERSHIPS

30+ reviewed

19 selected for in-depth analysis

4 PPP models developed

facturing Competitiveness (AEMC) Partnership to tackle two major goals through a multi-year initiative. The AEMC Partnership identified means to:

- Increase U.S. competitiveness in the production of clean energy products—by strategically investing in technologies that leverage American competitive advantages and overcome competitive disadvantages, and
- Increase U.S. manufacturing competitiveness across the board by increasing energy productivity—by strategically investing in technologies and practices to enable U.S. manufacturers to increase their competitiveness through energy efficiency, combined heat and power, and taking advantage of low-cost domestic energy sources.

Over a span of three years, the AEMC Partnership hosted nine regional dialogues and four national summits and obtained insights from industry, academia, national laboratories and government to drive U.S. competitiveness in manufacturing clean energy products, energy efficiency products and advanced manufacturing products. Among the most notable accomplishments of the AEMC Partnership are:

- The creation of the High Performance Computing for Manufacturing Program—a program of up to $3 million available to national labs to couple U.S. manufacturers with the national laboratories' world-class computational research and development expertise to address key challenges in U.S. manufacturing;
- The creation of the Clean Energy Manufacturing Analysis Center at the National Renewable Energy Laboratory; and

- The launch of a new "Technologist in Residence" to strengthen U.S. clean energy manufacturing competitiveness and enhance the commercial impact of its national laboratories.

The Council is proud to trace key accomplishments in manufacturing policy and innovation back to its thought leadership and advocacy, including the America COMPETES Act, Manufacturing USA—centers of excellence formerly known as the National Network for Manufacturing Innovation—and the National Digital Engineering and Manufacturing Consortium (NDEMC) that highlighted the regional importance of advanced computing. Each of these efforts brought together businesses, government and academia to meet grand technological challenges with the potential to unleash generations of American manufacturing innovation, jobs and prosperity.

The Energy and Manufacturing Competitiveness Partnership

In 2007, at the launch of the ESIS Initiative, the Council declared, "the cost of energy is clearly impacting the competitiveness of the United States. But the story does not end there. The economic toll exacted by maintaining the current state of U.S. energy, as well as the prospective windfall for ending it, has not been adequately captured or communicated in the context of national competitiveness." American energy strength and independence—once distant aspirations—are now within our grasp, with huge implications for America's global political, strategic and economic leadership.

Building on the promise of the ESIS Initiative, the Council's USMCI identified critical research, innovation and policy trends contributing to the re-emergence of America's high-value, advanced and productive domestic manufacturing sector—a key driver and beneficiary of these advances in energy technology, research and development.

Concurrent with the USMCI, the AEMC Partnership utilized dialogues, summits and the creation of public-private partnerships to identify and make recommendations to enhance U.S. competitiveness in manufacturing energy technologies and strengthen its foundations through increased energy productivity.

Through the ESIS Initiative, the USCMI, the AEMC Partnership and many other efforts spanning the last three decades, the Council and its members have contributed to a tectonic shift not only in how the United States consumes energy—with energy intensity levels steadily flattening and even declining, and improving relative to our competitors in Europe and Asia—but also in how the manufacturing sector can leverage energy abundance to create a competitive advantage if the right policies are put in place.

These two areas of our nation's economic and social fabric—manufacturing and energy—are deeply interconnected. America's ability to compete in the global economy, to rebuild the middle class and to steward its natural resources and environmental demands relies on coordinated, thoughtful policy solutions that leverage America's innovation ecosystem, workforce, technology, and business and policy-making communities.

The EMCP Methodology

On March 3, 2015, the Council officially launched the Energy & Manufacturing Competitiveness Partnership (EMCP) at a meeting hosted by Dr. William Powers, former president of The University of Texas at Austin. The C-suite conversation among 40 executives and experts from industry, academia, the national laboratories and labor catalyzed the private sector-driven effort to deepen understanding of a convergence between two forces essential to America's long-term productivity and prosperity: energy and manufacturing.

The EMCP was designed to approach the country's diverse industrial landscape as a network of distinct but interdependent productive sectors, each with its own challenges and opportunities. Through a series of sector studies hosted around the nation by members of the Steering Committee, the EMCP identified the salient questions and challenges facing the energy-manufacturing nexus within key sectors as identified by the Steering Committee. Seeking input from leaders throughout the private sector, academia, the research and scientific community, NGOs and government, each sector study looked at the challenges and opportunities through the Council's cross-cutting competitiveness pillars—technology, talent, investment and infrastructure.

Pillars of Competitiveness

Technology

- What role are energy abundance and innovation playing in increasing the productivity and competitiveness of American manufacturing? What innovations are occurring—or are urgently needed—for manufacturers to leverage natural gas, renewables and efficiency technologies to improve their competitiveness in the global marketplace?
- How is demand for new energy technologies impacting innovation, manufacturability and business outlooks for domestic technology manufacturing?
- How are energy and technology regulatory regimes impacting the competitiveness outlook of U.S. manufacturing across these sectors? What regulations and policy interventions could enhance innovation and accelerate the development and deployment of energy technologies and greater industrial energy productivity?

Talent

- What skills will define the 21st century energy and manufacturing economy? How is the private sector communicating needs to educators and students?
- What domestic skill shortages and talent deficits hinder America's ability to achieve the full potential of the new energy economy?
- What formal, alternative and continuing education platforms must be established or strengthened to ensure a robust talent pipeline and domestic workforce in these sectors?

Investment

- How are the tectonic shifts occurring across today's energy landscape—as the U.S. moves from "energy weak" to "energy strong"—changing the decision-making processes and competitiveness propositions for domestic and foreign manufacturers? And, what investments are U.S. manufacturers making in response to growing demand for new energy technologies, products, and services?

- How is America's energy abundance reflected in the competitiveness of sectors downstream from energy-intensive sectors of the economy?

- What hurdles do technologists, entrepreneurs and firms across sectors face in commercializing promising technologies and deploying them on a market-scale? What new institutions, mechanisms and knowledge-transfer systems must the investment community create to capture U.S. technology innovation and scale it domestically?

Infrastructure

- What investments in infrastructure—physical, educational, financial and beyond—are necessary to fully exploit the opportunity of America's growing energy strength and innovation ecosystem?

- In efforts to optimize the nation's full energy potential—and consequent competitiveness—how can policymakers and the nation's business, research and labor communities come together to resolve conflicts hindering the build-out the nation's energy infrastructure, including pipelines, the grid and new technology deployment?

Common challenges and opportunities illuminated key policy gaps and recommendations specific to each sector, and, equally as importantly, across these discrete sectors:

Water & Manufacturing

In February 2016, the Council launched the first phase of regional sector studies with a dialogue focusing on water and manufacturing. It was co-chaired by Dr. Michael Lovell, president, Marquette University and Mr. Ajita Rajendra, chairman & CEO, A. O. Smith Corporation. This first dialogue brought together more than 50 experts in the water and manufacturing industries for a closed-door conversation at Marquette University in Milwaukee. Common challenges were identified as well as opportunities relating to water, energy and manufacturing in the United States. *Leverage: Water & Manufacturing* was released at a press conference hosted by A. O. Smith Corporation in Milwaukee, WI, in September 2016.

Advanced Materials

Hosted at the Council's offices in Washington, D.C., and co-chaired by Dr. Laurie Leshin, president of Worcester Polytechnic Institute and Dr. Aziz Asphahani, president of QuesTek Innovations, LLC, the April 12, 2016 dialogue focused on challenges and opportunities regarding the design, production and scaling of advanced materials to accelerate the transition from discovery to manufacturing. *Leverage: Advanced Materials* was released in October 2016, at a briefing on Capitol Hill attended by key policymakers and representatives from industry, academia and the national laboratories.

Advancing U.S. Bioscience

In July 2016, EMCP members gathered for a dialogue on the role of bioscience in driving U.S. innovation in sustainable energy, chemical engineering, agriculture and food production. The meeting was followed by a briefing on Capitol Hill the next day, in which representatives from Council members Pacific Northwest National Laboratory and Lawrence Berkeley National Laboratory spoke to lawmakers on the applications for bioscience technologies.

The Council's efforts in this space continued, with the release of the fourth EMCP report—*Leverage: Advancing U.S. Bioscience*—at a widely-attended event on Capitol Hill in July 2017. Speakers at the briefing emphasized the importance of retaining America's leadership position in bioscience, and Congressman Randy Hultgren (IL-14) called for bipartisan, bicameral support of science leadership in the United States. These efforts continued into 2018, when the Council headed to Sacramento to present key findings before the state legislature.

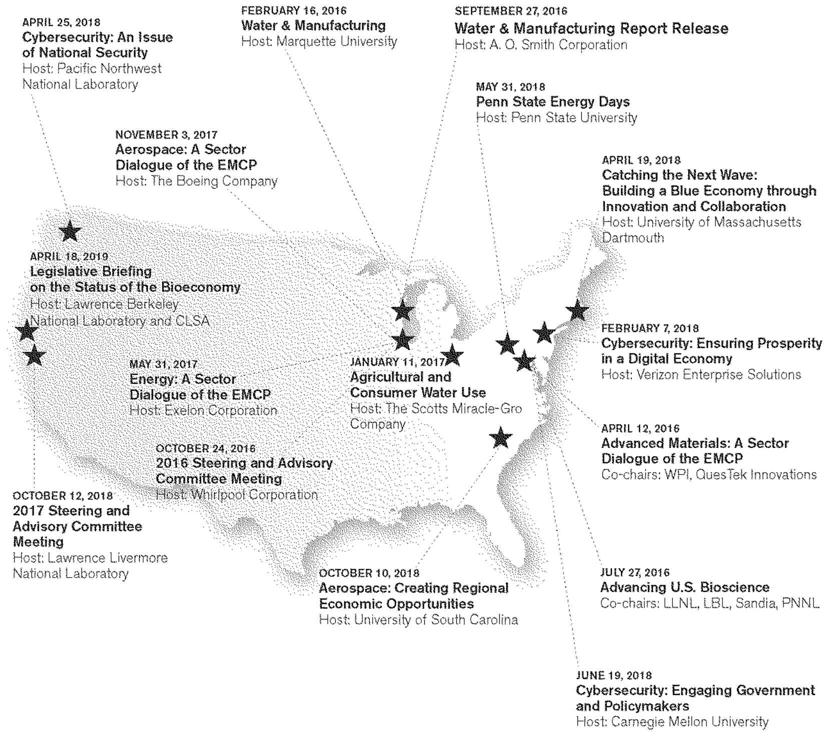
Agricultural and Consumer Water Use
In January 2017, the Council launched its second phase of sector studies with a dialogue on agricultural and consumer water use hosted by Mr. James Hagedorn, chairman and chief executive officer of the Scotts Miracle-Gro Company, at its headquarters in Marysville, OH. The dialogue was co-chaired by Mr. Hugh Grant, chairman and CEO of Monsanto Company. *Leverage: Agricultural and Consumer Water Use*, was released on World Water Day at an event hosted by Scott's Miracle-Gro in Florida and at the U.S. Water Partnership's annual meeting at the State Department in Washington, D.C.

Energy
Hosted in Chicago, IL, by EMCP Industry Co-chair Mr. Christopher Crane, president & CEO of Exelon Corporation, in partnership with Dr. Paul Kearns, director of Argonne National Laboratory, and Dr. Eric Barron, president of Penn State University, the Council convened in May 2017 a group of more than 30 experts to address the competitiveness of America's energy sector. The report, *Leverage: Energy*, was released at Penn State's Energy Days conference on May 31, 2018, in State College, PA, and will inform the Council's future work across and beyond energy and manufacturing.

Aerospace
In November 2017, the EMCP returned to Chicago for a dialogue on competitiveness in the aerospace sector, hosted by Boeing's Chief Technology Officer and Senior Vice President, Boeing Engineering, Test & Technology, Dr. Greg Hyslop, in partnership with Dr. Harris Pastides, president of the University of South Carolina. The final report, *Leverage: Aerospace*, was released at the South Carolina Aerospace Conference & Expo in October 2018.

Cybersecurity
In February 2018, the Council launched an effort to develop a national agenda on cybersecurity co-chaired by Dr. Steven Ashby, director of Pacific Northwest National Laboratory, Mr. George Fischer, senior vice president and group president of Verizon Enterprise Solutions and Dr. Farnam Jahanian, president of Carnegie Mellon University. The **National Agenda for American Cybersecurity** is informed by three dialogues hosted by the co-chairs, each of which drew on the expertise of practitioners and policymakers from industry, academia, government and the national laboratories.

Figure 5. EMCP Dialogues and Events



Challenges Identified by the Sector Studies

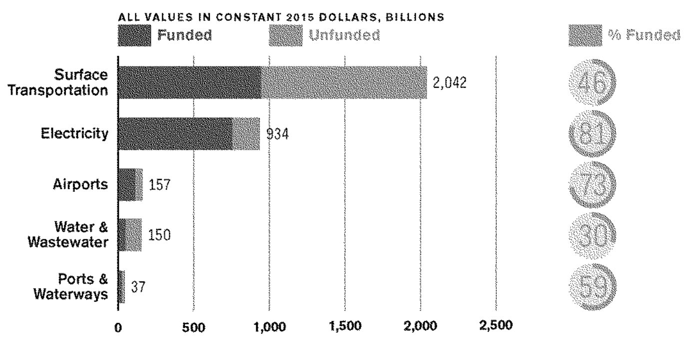
Outdated Infrastructure

A healthy modern economy relies on robust physical infrastructure to support productive economic activity. Yet, the Council's annual *Clarion Call for Competitiveness* report card has consistently given policymakers a D on addressing infrastructure needs. Similarly, the 2017 American Society of Civil Engineers report card on American infrastructure gives the United States an aggregate grade of D+ across 16 categories, estimating that $4.59 trillion will be necessary to improve critical infrastructure (see Figure 6).

When it comes to America's water infrastructure, approximately 1.7 trillion gallons of water are lost per year due to natural deterioration, damage and leaks resulting from aging infrastructure.[15] Land devoted to agricultural production across wide swaths of the United States is not water- or drainage-controlled, creating runoff and contamination issues for major waterways. In the energy sector, increasing consumption from the industrial sector and a heavy reliance on shale gas creates growing pressure on the extraction infrastructure.[16] And America's aerospace industry suffers from the constraints of a technologically- and financially-limited system that has fallen behind the satellite systems and business models of global competitors.

The challenges posed by this outdated infrastructure present a threat to U.S. competitiveness. America's infrastructure must be improved if the nation hopes to achieve its full potential.

Figure 6. America's Infrastructure Investment Gap
Funding needs of major infrastructure sectors in the U.S., 2016–2025
Source: ASCE



15 Challenge and Opportunity, The Value of Water Campaign, 2015.

16 For the First Time, Majority of Americans Oppose Nuclear Energy, Gallup, March 2016.

Regulation Not Keeping Pace With Innovation

Balancing regulation and innovation opportunity is a challenge constantly at the forefront of American competitiveness. While regulations are necessary to ensure new technologies meet the high safety and ethical standards of American society, smart policies must be enacted that allow the innovation ecosystem to develop and thrive.

There are numerous areas of policy that affect or are affected by technology-driven reorganization of the economy. For example, the current regulatory environment doubles the normal construction time of nuclear plants and offers investors only long-term returns on wind and solar investments. These policies incentivize producers to move to places like China where relaxed environmental regulations result in faster construction with higher returns. In the aerospace sector, which has been driven by technological innovation since its inception, drones and space-based technology present new ethical and security concerns that, if not collaboratively addressed by policymakers and industry, could hinder America's competitiveness in space exploration and travel.

Important steps are being taken. In 2017, Congress passed multiple pieces of legislation, including the 21st Century Cures Act, the American Innovation and Competitiveness Act and the National Defense Authorization Act that included provisions to help eliminate, reduce and streamline research-related regulations. But the rate of technological advancement continues to outpace the ability of regulators to react to innovation, widening the gap between the promise of new technologies and their applications.

"The national laboratories engage industry, academia and other stakeholders, both to help ensure success in their missions and to enable their cutting-edge research to have as broad an impact as possible."

Dr. William H. Goldstein
Director
Lawrence Livermore National Laboratory

The resulting regulatory uncertainty can discourage investment, new business formation and technology adoption, as well as hinder U.S. competitiveness in the long run.

Lack of Coordinated, Defined Research Agenda

Long-term technology leadership relies on strategic investments in research that push the frontiers of knowledge. Yet, many cutting-edge sectors lack clear, community-defined research agendas, often resulting in duplication of efforts and inefficient use of limited financial resources.

In the bioscience field, for example, the United States lacks a unifying roadmap, hindering strategic, long-term efforts and instead creating uncoordinated and disjointed programs and priorities. In the cybersecurity space, many in the private sector are calling for a consensus-driven prioritization of research questions and a mechanism for illuminating long-term challenges to better prioritize the allocation of limited research dollars.

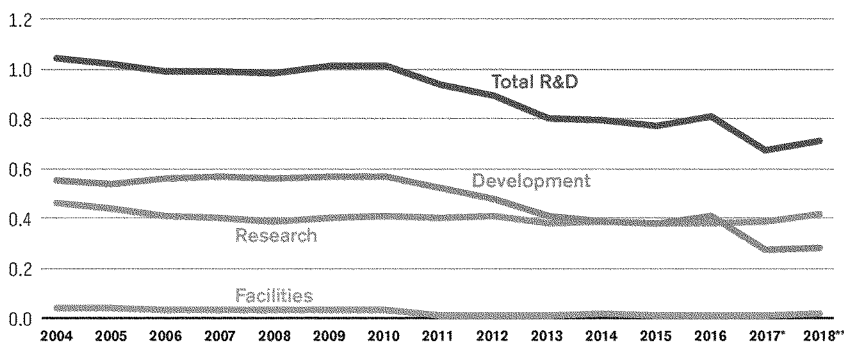
With limited federal funding available to support basic research, the need for coordination continues to grow. By incorporating a strategic agenda and streamlining the innovation process, the United States can better leverage outstanding research into global economic competitiveness.

Insufficient Research Funding

2018 was just the second time in a decade in which federal investment in R&D increased, hopefully indicating the reversal of a long-term trend and representing a step forward for the U.S. to regain its global innovation leadership (see Figure 7). But, public investment has not kept pace at a rate that will allow for the optimization of America's scientific assets, especially as companies have moved away from exploratory research toward nearer-term applied research and technology development.

Figure 7. Trends in Federal R&D as Percent of GDP, FY 2004-2018

Source: AAAS R&D report series, based on OMB and agency R&D budget data.



Note: Includes conduct of R&D and R&D facilities. Total R&D figures account for DOD adjustments to rectify differences in total obligational authority and new budget authority.

*Beginning in FY 2017, a new official definition of R&D has been adopted by federal agencies. Late-stage development, testing, and evaluation programs, primarily within the Defense Department, are no longer counted as R&D.

**FY 2018 figures are AAAS estimates based on omnibus-enacted appropriations.

Although federal investment in R&D is higher in the United States than any other individual country, several economies have greater R&D intensity—the ratio of R&D expenditure to gross domestic product (GDP). Over the last decade, R&D intensity in the United States has fluctuated only slightly. Yet, the U.S. rank in this indicator has been slowly falling in recent years: No. 8 in 2009, No. 10 in 2011, and No. 11 in 2013 and 2015.[17]

A focus on multidisciplinary funding is also critical—and tends to be insufficient—often due to structural, political and parochial concerns. This gap is particularly troubling as the diverse applicability of research cuts across multiple industries, including medicine, food, renewable energy and agriculture, among others. A lack of investment among cross-disciplinary fields or in a diverse collection of industries may inhibit promising advancements, thus hindering progress in these industries.

Looking solely at the private sector, while the United States maintains a decisive global edge in venture capital investment, which amounted to $66.6 billion and accounted for 86 percent of total venture capital investment in the OECD in 2016, the tendency of funders to allocate resources to projects with low risk and short-term payoffs hinders advancement in areas like the energy sector, where innovation is often characterized by extended project lifecycles.

Bringing Research to Market

While the federal government is the primary funder of basic research, the private sector, as innovators, investors and adopters, is pivotal when it comes to commercializing new technologies and bringing research to market. But, in many sectors, market incentives encourage low-risk, incremental improvements to technologies rather than the commercialization of radically new components and products.

When it comes to the water sector, affordability and awareness are significant impediments to the uptake of new and smart water and energy system technologies. Both the bioscience and advanced materials sectors face challenges in linking research to marketable industries and products, which can lengthen or even halt the discovery-development-deployment cycle. When it comes to the agriculture, lawn and garden and related industries, new, advanced products such as smart membranes, fertilizers and pesticides can improve water efficiency, but research and development is often cost-prohibitive. And in the aerospace sector, it can take 10-20 years for new materials to transition from design to deployment in the United States.

The ability to transition research to market is an essential leg of the innovation spectrum. Entrepreneurs are the conduits through which innovations appear in the market and create value. Entrepreneurs underscore the need to enable innovators to create successful startups that drive job creation and productivity growth and contribute to America's global competitiveness.

Insufficient Knowledge Sharing

The research and innovation ecosystem in the United States comprises a wide variety of stakeholders. Oftentimes, there is limited sharing of information across this landscape, which can lead to inefficiencies and duplication of efforts.

17 Science and Engineering Indicators, National Science Board, 2018.

In the materials sector, data gathered and entered into digital knowledge databases is extremely limited and under-developed, resulting in a significant amount of reliable data that cannot be utilized because it is not connected or curated. Regarding bioscience, quick and robust exchanges of information among industry and government partners, as well as within agencies of the federal government, remain a challenge despite the extensive infrastructure available to support innovation in the bioeconomy.

In other cases, the challenge is data collection rather than knowledge sharing. In the water space, for example, the amount of data available on water quality and efficiency is scarce. This lack of information often means issues go unrecognized until catastrophes arise. The United States also lags behind other parts of the world when it comes to developing and implementing the technology needed for weather forecasting and climate modeling, which hinders the agriculture sector's ability to manage and mitigate risk associated with changing weather patterns.

As the proliferation of data sweeps through modern industry, the challenges around collecting, validating and then sharing reliable information becomes central to America's industrial efficiency and competitiveness. Collaboration among public and private sector stakeholders will be essential to the United States' ability to maximize the potential of this wave of information.

Scientific Illiteracy

Science has a perception problem. One area in which this is particularly relevant is in the case of genetically modified food, which research shows to be safe, yet according to a recent ABC News poll of a random sample of 1,024 adults, 92 percent of Americans favor mandatory labelling for genetically modified foods and 46 percent do not believe genetically modified foods are safe to eat.[18] Greater science literacy is vital to combatting uninformed, negative perceptions of groundbreaking new technologies and products.

The challenges around creating an informed, scientifically-literate workforce begin with early education in the science, technology, engineering and mathematics fields. The Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA) 2015 data, for example, show that the U.S. average mathematics assessment scores were well below the average scores of the top-performing education systems. With regard to science achievement, U.S. fourth and eighth graders have not improved their international position since 1995—in fact, among the 17 education systems that participated in the 1995 and 2015 grade 4 TIMSS science assessments, the United States slipped in rank, from No. 3 in 1995 to No. 5 in 2015.[19]

At the professional level, insufficient scientific knowledge can translate into inefficiency. For example, when it comes to sustainable water management, neither the average consumer nor corporate leader typically understands the environmental and economic impacts of sustainable water use. This creates a barrier for the implementation of best practices at the industry and household levels that can carry significant costs.

18 Poll: Modified Foods Give Consumers Pause, David Morris, ABC News, July 15, 2018.

19 Science and Engineering Indicators, National Science Board, 2018.

The Skills Gap

Every instance of technological development requires the workforce to quickly adopt new skills to remain competitive and ensure innovation is leveraged to its maximum capacity. With the pace of innovation accelerating rapidly, the pressure to create a workforce with the skills needed to take on the jobs of the future is constantly mounting.

As one example, curricula at state colleges, junior colleges and universities are often misaligned with the changing needs of industry pertaining to managing water in the agriculture, lawn and garden and related industries. There is also a growing need for computing and data management skills among professionals in the water and agriculture space. In the bioscience industry, the talent pipeline is constantly evolving and now demands non-traditional biologists who have trained skills in multidisciplinary areas, such as computer science and ethics.

America's ability to prepare its workforce for current and future opportunities is a key aspect of the country's ability to remain competitive and must be collectively addressed by policymakers, industry and academia.

The Changing Workforce Demographic

As the skills required to participate in the workforce change, so does the structure of the workforce—further complicating the challenges industry faces now and in the future regarding securing the talent necessary to succeed.

"The education and skills necessary to compete and prosper are changing rapidly and it's critical that universities respond and adapt to ensure our students are prepared to excel in this evolving economy."

The Honorable Rebecca Blank
Chancellor
University of Wisconsin–Madison

One particular shift in the United States is the aging of the baby boomer generation. 2017 marked a peak in the number of Americans collecting Social Security benefits, up nearly 2.4 times the number of total beneficiaries in 1970.[20] Moreover, over 50 percent of utility workers are set to retire in the next decade.[21]

At the same time, the disappearance of industrial arts and vocational training in K-12 education has made it more difficult to find talent for the manufacturing sector. In fact, a 2014 survey by Deloitte revealed that respondents between the ages of 19 and 33 would be least likely to select a manufacturing career among the options presented.[22]

20 Table: Number of beneficiaries receiving benefits on December 31, 1970-2017, Social Security Beneficiary Statistics, Social Security Administration.

21 Who will Replace Nuclear Power's Aging Workforce?, Russell Ray, Power Engineering, February 5, 2015.

22 Overwhelming Support U.S. Public Opinions on the Manufacturing Industry, Deloitte United States (Deloitte Development LLC) and The Manufacturing Institute, 2014.

While America's industry executives have made clear that finding and developing talent is of the highest priority, it remains true that without action the skills gap is likely to leave up to 2 million American jobs unfilled over the next decade (see Figure 8).[23]

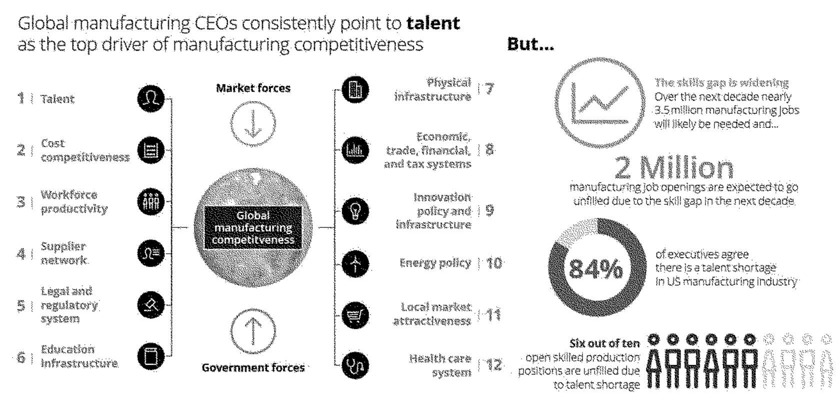
Increasing Global Competition

Globalization and the increasing technological and innovation capabilities of countries worldwide are changing the competitiveness landscape drastically. In 2016, worldwide total R&D expenditure grew 3 percent, indicating that countries around the world are increasing R&D funding for innovation.[24]

The global private sector is becoming increasingly involved in the funding of R&D as well, with business sectors in Germany, China, South Korea and Japan funding as much as 78 percent of R&D compared to 62 percent in the United States.

The strategies for allocating R&D funds vary globally as well. While the United States focuses more heavily than many of its competitors on basic research, with 17 percent of R&D funds to China's 5 percent, China dedicates 84 percent of its R&D spending to experimental development and moving new technology to market compared to 64 percent in the United States.[25]

Figure 8.



Sources: Deloitte Touche Tohmatsu Limited and US Council on Competitiveness, *2016 Global Manufacturing Competitiveness Index*; Deloitte and The Manufacturing Institute, *The skills gap in US manufacturing: 2015 and beyond*

23 2014 Skills Gap Study, Deloitte and The Manufacturing Institute.

24 Global Innovation Index 2018.

25 Science and Engineering Indicators, National Science Board, 2018.

As the global landscape changes, international competition increases. While the United States reached a five-year high rank of No. 4 in the Global Innovation Index (GII) in 2017, the nation dropped to No. 6 in 2018 (see Figure 9). And, in key areas such as regulatory environment, infrastructure and education, the nation ranks No. 12, No. 24 and No. 47 respectively.

With regard to investment in specific sectors, more than 40 countries have shown interest in promoting the bioeconomy, and many have strategic plans in place to create a competitive bioeconomy in their respective countries. This includes China, which has called for hundreds of billions of dollars to fund the application of biotechnology in the healthcare sector.

When it comes to measuring water quality and scarcity and implementing strategies to mitigate risk in these areas, the U.S. is falling behind countries like Australia and Israel, which have made significant investments in this area. And countries such as Singapore, Portugal and Denmark are becoming leaders in incentivizing and implementing advancements in the aerospace sector.

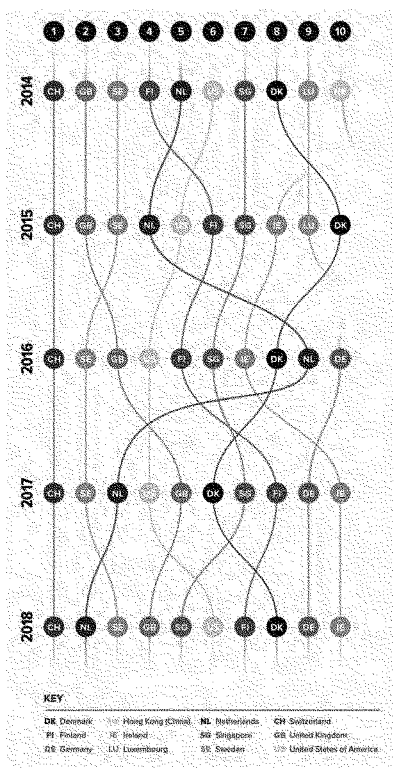
Another indicator of rising global competition is an increase in the number of science and engineering graduates. Between 2000 and 2014, the number of science and engineering (S&E) bachelor's degrees awarded in China rose more than 350 percent, significantly faster than in the United States and in many other European and Asian regions and economies.[26]

As nations begin to recognize the advantages of investing in a strong innovation ecosystem, the United States must re-prioritize science and technology to remain a global leader.

26 Science and Engineering Indicators, National Science Board, 2018.

Figure 9. Movement in the GII Top 10

Source: *The Global Innovation Index 2018: Energizing the World with Innovation*, Global Innovation Index Database, Cornell, INSEAD, and WIPO.



Emerging Cyber Threats

The interconnectedness and openness made possible by the Internet and the broader digital ecosystem create unparalleled value for society. Over 20 billion devices are expected to be connected to the Internet by the year 2020. However, these same qualities make securing today's cyber landscape difficult.

As the United States continually advances and modernizes its energy systems, efficiency is sometimes prioritized over security, making grid and nuclear plant monitoring a significant concern. In the aerospace sector, the increasing density of aircraft in the skies leads to a higher need for communication between the air and the ground, making cybersecurity an area of particularly high importance. Yet, in a 2015 survey conducted by the Airport Cooperative Research Program and sponsored by the Federal Aviation Administration, only 34 percent of airport respondents indicated they had implemented a national cybersecurity standard or framework.[27] And as more industries see the proliferation of sensors and monitoring equipment, the surface area of connected devices continues to grow exponentially—creating more room for infiltration.

Despite the notable risks cyber threats pose to American prosperity, there remains a wide disparity in investment, maturity, coordination and training on cybersecurity across the country's critical infrastructure sectors. The White House Council of Economic Advisers estimates that malicious cyber activity cost the U.S. economy between $57 billion and $109 billion in 2016, and estimates costs to reach $2.1 trillion globally by 2019. If stakeholders across government, academia and industry fail to implement strong, coordinated cybersecurity strategies and practices, the United States will become increasingly vulnerable to the growing cyber threat.

In response to these challenges, the Council developed, and has put forth in this report, a Call to Action to turbocharge the U.S. manufacturing renaissance in an era of energy abundance (see pages 9-12). In addition, *Secure: Ensuring Resilience and Prosperity in a Digital Economy* is being simultaneously released under separate cover. The Council's National Agenda for Cybersecurity can be found in Appendix A on page 66.

27 *Guidebook on Best Practices for Airport Cybersecurity*, Airport Cooperative Research Program, 2015.

Moving Forward

The United States is at a critical moment in time in national innovation systems research and action. New, transformational models driven by the democratization and self-organization of innovation are emerging and taking root across the nation.

These developments, which were called out in the 2017 Council report *Transform*, are occurring against the backdrop of increasing global, innovation-based competition and growing capacity for innovation in countries around the world. *Transform* went on to highlight rising internal challenges in the U.S. innovation system—such as changing demographics, lack of diversity and inequality of opportunity in the U.S. education system—that are changing the shape of the U.S. workforce. In response, innovation practitioners and stakeholders are facing difficult questions about how individuals, teams, communities and national institutions of knowledge creation and innovation will transform to support current and future U.S. innovation.

As changes in the process of innovation unfold, increasing attention is being paid to the science of the innovation process itself, and how to reduce its risk and uncertainty. Researchers and academics have contributed for decades to the field of corporate management, and are now beginning to focus their attention on new types of organizational structures, and methods to accelerate and optimize technology commercialization.

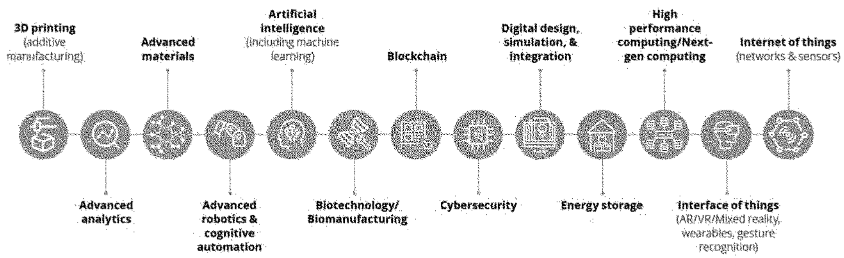
The recommendations in this report—and the over ten years of work they encompass—have the power to turbocharge America's manufacturing capabilities, improve America's competitiveness and unleash a new wave of productivity and prosperity for all Americans. But more work remains to be done. U.S. leadership is under threat. The United States faces now what are perhaps existential challenges to its global leadership in innovation. America's role in technology advancement is diminishing globally—now accounting for only one-quarter of global research & development, down from two-thirds in 1960. Competitors around the globe are increasing their capacity for innovation. And rapid technological change and disruption have impacted the workforce and communities.

As Figure 10 highlights, there are numerous exciting, disruptive technologies and tools just beginning to impact the global economy that have the potential to completely change the way people travel, shop, build, explore and interact. And the impact on companies and universities is likely to be just as consequential.

With these challenges in mind, in 2019, the Council will launch a **National Commission on Innovation & Competitiveness Frontiers** to double down on all efforts to optimize the nation for this new, unfolding innovation reality. The Commission will build on the Council's intellectual capital in this space developed over the past thirty years, including the recently

Figure 10. A Snapshot of Exponential Technologies

Source: Deloitte, Council on Competitiveness, Singularity University. 2018. *Exponential Technologies in Manufacturing.*



completed two-year partnership with the National Science Foundation—the Exploring Innovation Frontiers Initiative—that culminated in the release of *Transform*. Organized around three critical competitiveness pillars—capitalizing on emergent and converging technologies; optimizing the environment for innovation systems; and exploring the future of production, sustainable consumption and work—the Commission will acknowledge and respond to the urgency of the challenge at hand, understand and describe this new reality and position the nation to prosper and thrive with a clear set of recommendations that will enhance and expand the nation's innovation capacities at the heart of competitiveness.

Sector Study Overviews and Recommendations

Water & Manufacturing

CO-CHAIRS

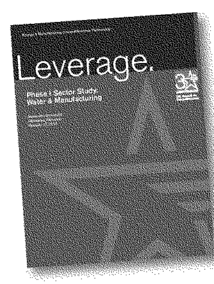
Dr. Michael Lovell
President
Marquette University

Mr. Ajita G. Rajendra
Chairman & CEO
A. O. Smith Corporation

Water is necessary for industry, society and individuals to survive and thrive. Nearly half of industry water consumption is attributable to manufacturing products and services.[28] As fundamental changes such as urbanization and population growth take hold, innovation is needed in infrastructure, technology, investment and talent to meet the increasing demand for water. This requires taking a stewardship approach in which all sectors come together to look beyond compliance and view water as a finite resource that must be managed efficiently.

The EMCP sector study dialogue on water & manufacturing, hosted on February 16, 2016 by Marquette University in partnership with A. O. Smith Corporation and the Council, gathered national leaders and water experts from all sectors of the economy to discuss the important issues around water and manufacturing. The day, broken down into four sections—talent, technology, investment and infrastructure—featured robust conversations on these key pillars.

Leverage: Water & Manufacturing was released in September, 2016 at a press conference hosted by A. O. Smith Corporation in Milwaukee, WI. The event was widely covered by local radio, TV and print media.



Findings and Recommendations

- **Use a stewardship approach to water management in which laws and regulations surrounding water reuse support natural processes whenever possible and treat water as the limited resources it is rather than a limitless commodity.** Industry uses approximately 350 billion gallons of water each day, nearly half of which is attributable to manufacturing products and services. In some countries, safe water supply has the potential to increase GDP up to 7 percent, making it increasingly important to understand the true value of water and price the commodity appropriately in order to improve efficiency.
- **Integrate natural infrastructure, including roof installments, rain barrels and constructed wetlands, into water management approaches to improve energy efficiency and water quality while reducing overall water infrastructure investment costs.** Green infrastructure is often considered a cheaper and more sustainable alternative to water management than traditional gray infrastructure. Operations and maintenance

28 Water and the Economy, Water's Value, The Value of Water Coalition, 2015.

costs for natural infrastructure projects such as constructed wetlands can be dramatically lower than those associated with traditional wastewater treatment alternatives, with green infrastructure in general presenting a cost savings of more than $1.5 billion. These projects also often have additional ancillary benefits for the community and environment and help companies comply with EPA water discharge requirements.

- **Encourage development and deployment of technologies and microbiological barriers that increase overall water supply by diversifying sources and improving quality and efficiency such as desalinization, nutrient recovery and wastewater re-use.** As America's population increases and converges on cities, demand for fresh water and dependence on reliable water infrastructure will grow exponentially. The resulting need to diversify water sources presents a distinct opportunity for these types of innovative solutions such as the development of advanced materials that can remove specific compounds in a more efficient manner.
- **Promote the uptake of sensors and monitoring equipment and aggregation of big data across sectors and geographies to improve water management and increase information available on water quality and efficiency.** Data on efficiency and water quality is scarce. This lack of information often means issues go unreported until catastrophes arise. Increased access to knowledge would allow water issues to be addressed proactively before they reach a point of crisis.
- **Increase federal funding available for water technology test beds to accelerate development and reduce cost and risk associated with deployment of advanced technologies for improving water quality and efficiency.** Affordability and awareness are significant impediments to uptake of new smart water and energy system technologies necessary for the water industry. Government funding and strategic placement of these testing facilities near the companies investing in new water technologies would de-risk the adoption of these technologies.
- **Model water consumption and availability using high performance computing to address gaps in supply and demand and reduce overall waste and costs associated with managing water and energy systems.** Approximately 1.7 trillion gallons of water are lost per year due to natural deterioration, damage and leaks resulting from aging infrastructure. The use of new sensors and measurements, as well as high performance computers, would facilitate collection and dissemination of data in a universally accessible and understandable fashion.
- **Engage government and private sector stakeholders in an enhanced public awareness campaign to address water conservation needs.** Given the current pricing structure of water, neither the average consumer nor company fully understands the importance of conserving this resource. Social marketing and public awareness campaigns can elevate the visibility of water-related issues. This would likely include collaboration with existing initiatives to enhance the overall reach and level of knowledge regarding water issues among consumers.

- **Address the skills gap in the water and manufacturing sector by de-stigmatizing technical careers, reintroducing hands-on training in K-12 and encouraging cross-sector partnerships between industry and academia.** 2016 marks a peak in the number of people on social security benefits, amounting to nearly 2.4 times the number of total beneficiaries in 1970. This creates a skills gap in which talent is not properly matched with available jobs. Partnerships between technical colleges and industry can bring talent directly onboard and highlight specific skill sets to produce a strong talent pipeline.

Advanced Materials

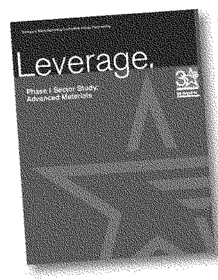
CO-CHAIRS

Dr. Aziz Asphahani
Chief Executive Officer
QuesTek Innovations LLC

Dr. Laurie Leshin
President
Worcester Polytechnic Institute

Advanced materials are critical building blocks that can drive significant enhancements in America's energy production, manufactured products and the overall economy. Early adoption of advanced materials by manufacturers can differentiate U.S. products from those of competitors by increasing performance and durability, decreasing production and maintenance costs and improving energy efficiency over the life cycle use of the product. Use of these new materials in commercial products also drives the market for the materials themselves.

The EMCP sector study dialogue on advanced materials, hosted on April 12, 2016, by the Council on Competitiveness in partnership with QuesTek Innovations, LLC and Worcester Polytechnic Institute convened national leaders and materials experts from all sectors of the economy to discuss how the development and deployment of advanced materials can increase U.S. competitiveness. The day focused first on the current capabilities in U.S. national labs, universities and across the private sector in advanced materials, barriers and impediments to fully deploying the promise of advanced materials across the manufacturing and energy sectors and solutions to these challenges.



Leverage: Advanced Materials was released at a briefing on Capitol Hill in October, 2016. Panelists included representatives from the Council, QuesTek Innovations, LLC, Worcester Polytechnic Institute and Lawrence Livermore National Laboratory, who shared the key findings and recommendations with policymakers.

Findings and Recommendations

- **Promote the uptake of more public private partnerships (PPP) between the national laboratory system and industry partners, small businesses and universities.** The development stage of materials is suffering when it comes to scaling-up materials for mass production and use. Small and medium-sized businesses must have consistent access to laboratory spaces and other critical infrastructure and technologies. PPPs would allow designers to develop new innovative products, and the gathering of key university experts to perform fundamental research in science, engineering and technology areas under one location would connect American manufacturers to global markets.

- **Develop a national knowledge platform to ensure that accurate, pedigreed, curated and easily accessible data is developed to support the creation, processing, modeling and manufacturing of advanced materials.** The current digital knowledge database on materials is extremely limited and underdeveloped. As a result, there is a significant amount of usable data that cannot be absorbed because it is not connected or curated. The leap forward for technology in the area of advanced materials will likely come from the broad dissemination of tools with interoperability as a key enabler.
- **Gather critical masses of materials experts into business groups or entities to work with materials technologies as a collective effort to combine distinct knowledge bases and spur unique funding opportunities.** Materials experts operate separately from one another, which creates gaps in data management and further complicates the standardization needed to advance this field. Cross-functional collaboration throughout and between various small and medium-sized businesses can become part of leading expert groups specializing in accelerating both discovery and development of materials.
- **Dedicate area-specific pilot-plant facilities to collaborate with national laboratories, universities and small and medium-sized companies to accelerate deployment and decrease the commercialization time horizon for advanced materials.** Industry access to scientific and technical resources will help manufacturers develop and deliver new, innovative products to market and qualify materials in faster-paced, more efficient systems. Such pilot-plant facilities will help decrease the expected deployment time and accelerate the entire discovery-to-deployment cycle. In the absence of private sector support of the needed pilot-plant facilities, it is recommended that government agencies (e.g., DoE, DoD, NIST) take the lead by establishing a "Materials Genome Processing Center", as the first pilot-plant facility that is needed to achieve the Materials Genome Initiative (MGI) goal of ensuring a manufacturing infrastructure for materials innovations.
- **Address the skills gap in the advanced materials and manufacturing sector by embracing an interdisciplinary approach to education that combines traditional materials science curricula with data science, modeling and simulation and computational sciences.** A recent survey revealed that respondents between 19 and 33 years old would select a manufacturing career last. Reintroducing hands-on training at the K-12 level can address the misconceptions around the manufacturing sector and lack of knowledge regarding the emerging opportunities in advanced manufacturing, while partnerships between academia and industry

designed to nurture cross-disciplinary skill sets at the undergraduate and graduate levels can ensure a strong talent pipeline.

Advancing U.S. Bioscience

CO-CHAIRS

Lawrence Berkeley National Laboratory

Lawrence Livermore National Laboratory

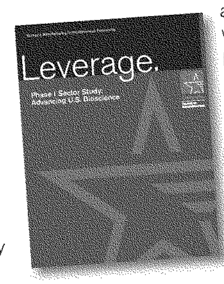
Pacific Northwest National Laboratory

Sandia National Laboratories

Bioscience is a top manufacturing technology priority across the federal government and is critical for U.S. competitiveness. While the United States maintains a world leadership position in engineering biology and bioscience technology development, other countries are investing heavily in these areas putting the U.S. at risk of losing its competitive advantage.

The EMCP sector study dialogue on advancing U.S. bioscience, hosted on July 27, 2016 by the Council on Competitiveness in partnership with Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, Pacific Northwest National Laboratory and Sandia National Laboratories gathered national leaders and experts on the bioeconomy to discuss the importance of bioscience to U.S. competitiveness. The day-long session focused on the actions needed to be taken in the United States to capitalize on the capabilities and individual successes across the bioscience landscape. The following afternoon, the Council and leaders from industry and the national laboratories briefed congressional staffers at a joint program between the American Society of Mechanical Engineers (ASME) and the House Manufacturing Caucus.

In July 2017, ***Leverage: Advancing U.S. Bioscience*** was released before policymakers, experts, and representatives from industry and academia at a senate briefing on Capitol Hill, where over 100 participants heard from Council members as well as Representative Randy Hultgren (IL-14), who underscored the importance of U.S. leadership in this space.



The conversation continued in April, 2018 when the Council partnered with the California Life Sciences Association to provide a briefing in Sacramento to members and staff of the California State Legislature on the status of California's bioeconomy and to discuss opportunities to leverage the state's assets in this space.

Findings and Recommendations

- **Develop an annual strategic roadmap for the advancement of bioscience and biotechnologies to meet energy, environmental, agricultural, national security and economic goals.** The Office of Science, Technology and Policy (OSTP), research agencies, industry, national laboratories and academic experts should partner for the purpose of creating a Bioeconomy Roadmap to be implemented as a top economic priority of the incoming administration.

- **Create tools and processes that capture and analyze basic applied research data, private sector and government-funded activities, and community feedback on the Bioeconomy Roadmap's goals, objectives and milestones.** With the 2012 National Bioeconomy Blueprint 1 as its foundation, a performance indicator document is needed to review the progress of various aspects of bioscience research on a yearly basis. Information pertaining to the success of policy and science programs such as data analysis, workforce development, regulatory barriers and future federal activities will leave researchers better equipped to establish areas of improvement and increase public awareness of the importance of the bioeconomy.
- **Coordinate investments across government agencies, broaden disbursement to cross disciplinary fields, and focus federal investment in the development of research platforms that more quickly deliver solutions to society.** The diversity of bio-based products cuts across multiple industries like medicine, food, renewable energy, agriculture and many more, creating challenges when coordinating investments. A lack of investment among cross-disciplinary fields or in a diverse collection of industries may inhibit promising advancements, therefore hindering forward movement for bioscience as a whole.
- **Address the issue of public distrust of science and regulation by raising awareness and increasing education and outreach efforts to the public and policymakers.** The public perception of bioscience as a whole is incredibly important to moving forward, and scientists must remain ethically grounded to gain public trust. Combatting uninformed, negative perceptions requires improving U.S. scientific literacy through an education and outreach program that includes STEM education and progress metrics.
- **Provide opportunities and incentives for stakeholders to determine next generation bio-targets that biotechnologists can use to reinvent products and make them marketable to consumers.** The notion of using biotechnologies to recreate products with next generation applications, like chemicals and fuels that release fewer toxic gases into the atmosphere, simply does not have a strong enough economic value that will appeal to the consumer. Biotechnologists need a target with both next generation properties and next generation values in order to succeed in the market.
- **Develop widespread and easily accessible knowledge bases of principles, methods, processes, successes and failures to more quickly deliver helpful information to stakeholders.** Industry access to central scientific and technical resources will help experts develop and deliver new, innovative products to the market. This will improve the maturation and impact metrics of the bioeconomy and assist in the technology innovation pipeline from development in the laboratory to scaling-up in the manufacturing plants on to consumer outlets.
- **Enable bioscience research platforms to deliver novel and cost prohibitive capabilities to industry.** From start-ups to large companies, academic and agencies' scientists, federal and industry investments in research platforms and

bioscience knowledge bases will help overcome the steep barriers to entry for biomanufacturing and product development.

- **Address the talent gap in multidisciplinary areas where bioscience has evolved to require frequent translation of information, updating of codes, and data management skills in high performance computing.** The bioscience talent pipeline has significantly transformed and now demands non-traditional biologists who have trained skills in multidiscipline areas. There must be a frank dialogue among industry and academic leaders about workforce development so we can reestablish training and employment opportunities for graduating students and continue to expand science beyond its current capabilities.

Agricultural and Consumer Water Use

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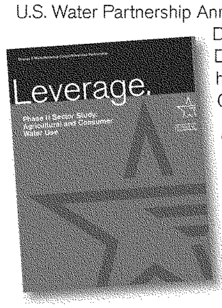
American agriculture—including the related industries and value-add sectors that fuel and depend upon it—is a case study in innovation-driven productivity and competitiveness, and one of the United States' largest exports. Since World War II, investment and R&D in agricultural science, technology, and land and resource management have increased the agricultural industry's energy productivity by nearly 100 percent. Agricultural products and technologies remain a key component of American exports, and are a key factor in the growth of the domestic service and manufacturing economy, supporting restaurants, tourism, apparel, furniture and design.

Competition for water, climate change and new consumer demands are also driving change in the agriculture, lawn and garden, and related industries, including greater interest in new products and sustainable production processes. A changing legal and regulatory environment is facilitating the entry of new products into the market, while increasing the already competitive demand for water and energy. Inputs across the agricultural value chain are evolving, which begs a new set of questions regarding innovation and efficiency in growing and manufacturing processes.

The EMCP sector study dialogue on agricultural and consumer water use gathered national leaders and experts on water as it relates to these industries to discuss the implications for U.S. competitiveness. The day-long session focused on the role of subsidies in driving or hindering sustainable water use, the implications of increasingly unpredictable weather patterns for the agriculture, lawn and garden, and related industries, and the need for infrastructure—both regulatory and physical—and a workforce appropriately equipped with the skills necessary to manage water quality and quantity.

Leverage: Agricultural and Consumer Water Use was released on World Water Day in 2017 at the U.S. Water Partnership Annual Meeting at the State Department in Washington, DC, as well as at an event hosted by Scott's Miracle-Gro in Florida.



Findings and Recommendations

- **Invest in the technology needed to better model climate data.** As an issue that impacts the competitiveness of multiple U.S. industries, the government and the private sector must invest in the development and deployment of technologies that monitor total soil health, ocean temperatures and other climate predictors to allow farmers and researchers to better monitor and model weather patterns.
- **Create a verification system for crowdsourced data related to weather patterns and agricultural processes and inputs to facilitate a trustworthy knowledge database that comprises public- and private-sector information.** Collaborative public data can significantly increase precision and automation in water management and improve modeling capabilities and predictive future planning of crops, while improving climate forecasting in the critical three to nine month period. A verification system around individually reported data would filter quality data and allow for better, more efficient convergence of public- and private-sector data.
- **Leverage high-value crops as a test bed for innovation.** New, advanced materials such as smart membranes, fertilizers and pesticides can improve water efficiency, but research and development is often cost-prohibitive. Testing smart materials and other high-cost innovations on high-value crops would promote innovation by reducing the financial risks in the early stages of product development.
- **Better align subsidies on agricultural products with water efficiency and conservation goals.** Financial incentives and regulations must look at the entire landscape comprehensively to encourage smart water management and insulate against negative externalities, including heavy water use in water stressed areas and spiraling commodity prices.
- **Develop industry standards and disclosure processes for water use.** Financial disclosure, and more recently carbon and other climate related disclosures, are important aspects of a company's license to operate. Using baseline measurements can improve overall understanding of water use and allow for better monitoring of business operations' effects on the quantity and quality of the water they use and return to the environment. These baselines also encourage cost-saving efficiency improvements with the co-benefit of positive environmental and community-level impacts.
- **Encourage the use of reclaimed water in place of potable water where possible for landscaping needs.** Using reclaimed wastewater, which is most commonly used in irrigation, has the potential to significantly lower landscaping costs.

Increasing urban and industrial use of recycled water can be a cost-effective way to increase water supply without drawing from a limited supply of groundwater and freshwater. Many states throughout the United States have adopted guidelines for recycled water use.

- **Better align training and education programs to increase the pool of experts with skills in water management.** Educational requirements at state colleges, junior colleges and universities in horticulture and related areas often lack the appropriate level of focus on water conservation and management. This is in part due to a lack of state-level funding in the absence of extreme conditions such as drought. Increased alignment between industry and academia at the undergraduate and postgraduate levels is necessary to produce a strong talent pipeline.
- **Train upper-level managers with the skills needed to recognize the technical requirements around water management during the hiring process.** While the pool of engineers and professionals trained in water management is small, there is also a gap in knowledge among upper-level managers with regard to hiring employees with the proper skills to implement sustainable water systems and practices. A top-down approach is needed to better integrate water management into core business strategy, particularly in less densely populated areas where there is increased difficulty attracting top talent.

Energy

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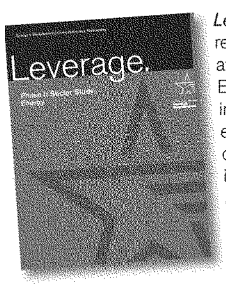
Energy is the linchpin of economic growth and prosperity. In its abundance, low-cost, efficient energy can create a competitive advantage for the United States, enabling increased productivity and efficiency across industries. The country's commitment to energy efficiency has helped not only to reduce the negative environmental impacts associated with heavy industrial and consumer reliance on energy, traditionally in the form of coal and other fossil fuels, but also to reduce costs and drive innovation and competitiveness.

As the world sits on the precipice of a clean energy revolution, energy resides as an attractive investment that both supports preserving the nation's existing zero emission technologies and enables new technologies and innovative strategies to reduce our carbon footprint and remain sustainable for generations to come. But America's energy security is also an issue of national security. As we continue to advance and modernize America's energy systems, it is important to ensure grid modernization does not occur at the expense of security. Monitoring cyber activity and guarding against infiltrations of America's grid and nuclear plants are a significant concern, and grid security is a national security risk of the highest order.

The Council on Competitiveness hosted the Energy and Manufacturing Competitiveness Partnership (EMCP) sector study dialogue on energy on May 31, 2017 in partnership with Exelon Corporation, Penn State University and Argonne National Laboratory to address these and other current issues in the energy economy. The dialogue focused on strategies for a sustainable, economically viable energy future that satisfies the sometimes-competing needs of consumers, industry and the environment.



Leverage: Energy was released in May, 2018 at Penn State's annual Energy Days conference in State College, PA. The event was attended by over 200 experts from industry and academia, and included a follow-up conversation linking the report and recommendations to Pennsylvania's energy opportunity to create regional prosperity.

Findings and Recommendations

- **Implement regulatory policies that encourage the preservation, development and implementation of more efficient, clean energy solutions.** With gains being made in efficient energy technologies, the United States is becoming more self-reliant and even an exporter of energy and energy technologies. The approach of preservation and investment provides a comparative advantage in many fuel-based sectors of the economy, increases cost-efficiency in major manufacturing sectors and promotes investment in existing and new technologies. Policymakers and regulators in the United States must embrace new scientific discoveries and modeling and simulation technologies to maximize efficiency for non-renewable energy sources and increase production of clean energy.
- **Direct funding and investment toward innovation in energy storage capabilities and clean energy technology.** It is widely accepted that innovation is responsible for one third of gains in economic growth in the United States. For example, by shifting focus toward innovation, nuclear plants have been able to increase operating capacity from 60 percent to more than 90 percent in the past 30 years. Policymakers must create incentives that accelerate the pace of change in the energy sector, which would allow for more immediate returns on innovation as well as future economic development. This includes modernizing the energy grid, updating our energy infrastructure, preserving the nation's zero emission resources and focusing on clean, resilient and renewable energy sources.
- **Secure America's critical energy infrastructure from cyber attacks.** According to the Department of Homeland Security, last year, of the cyber incidents targeting industrial control systems in the 16 infrastructure sectors designated as critical, 20 percent were in the energy sector. Technological advancements made in favor of

energy efficiency are outpacing security and will continue to do so unless we change the way we approach and implement cybersecurity strategies and practices. Protecting America's energy infrastructure against cyber-attacks is an issue of national security, and requires a model for valuation of cybersecurity and best practices that includes input from a diverse group of stakeholders from industry, academia and government.

- **Utilize national labs to develop innovative energy technologies.** The national labs, when provided appropriate funding, have the means to design improvements for reliable and efficient energy equipment such as wind turbines or oil and gas drills that are cost-effective and less prone to traditional wear. By investing in national labs and making their resources available to private entrepreneurs and innovative startups, researchers can hope to foster major technological breakthroughs in the areas of energy production and storage.
- **Guide research to the market and provide guidance on where investment can be most impactful to speed the commercialization of new technologies.** Building the bridge between universities, national labs and the business world is critical to ensure research is not stranded in universities or labs. Universities, companies and the federal government must ensure adequate and predictable R&D spending to foster technological development and the federal government must encourage investments that put the United States in a more competitive position.
- **Encourage a multidisciplinary approach to education that includes opportunities for students to learn technical skills, soft skills, teamwork and critical thinking skills from early development through post-graduate education.** Education must distance from teaching by syllabus as this stifles creativity. Policymakers must provide funding for technical education in high schools and give students hands-on training while de-stigmatizing well paying "blue collar" jobs. Students should have access to occupational engineers in hands-on problem solving, and teachers must continue to learn and communicate with industry experts to evolve science curriculum.
- **Encourage lifelong learning opportunities that allow students to gain more skills and stack credentials.** Every time a new technology is developed, there must be a ripple of new training within the industry so workers can operate these new machines and researchers can build on intermediary technologies to develop breakthrough inventions. Utilities, technical companies and labor unions can ensure their current employees' skill sets are meeting the evolving needs of the energy industry by providing education opportunities to people across diverse ages and stages of their careers.

Aerospace

CO-CHAIRS

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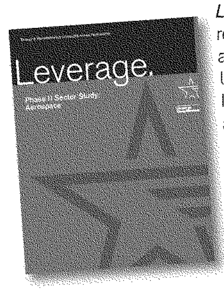
Chief Technology Officer
The Boeing Company, and
Senior Vice President
Boeing Engineering, Test & Technology

Dr. Harris Pastides
President
University of South Carolina

The United States is on the verge of another golden age in aerospace. Encouraging innovation the aerospace sector goes beyond U.S. competitiveness and is at the core of America's imagination. Freeing people from the confines of terrestrial travel is on the horizon and will change the world significantly. Whether aerospace manufacturing will ever reach an automotive scale, however, is still uncertain.

As a critical economic incubator for emerging businesses, the aerospace industry can provide job opportunities to help offset the loss of traditional U.S. manufacturing positions. Given the importance of aerospace business to U.S. innovation and economic progress, the industry receives strong bipartisan support from policymakers. The United States is, however, at risk of losing a key opportunity to gain an economic advantage in a growing business sector as advancements in technology, talent, investment and infrastructure on the part of global competitors begins to outpace that of the United States.

In this sixth sector study of the Energy and Manufacturing Competitiveness Partnership (EMCP), the Council on Competitiveness' dialogue on competitiveness in the aerospace sector gathered experts to identify friction points, ideas and challenges facing Introduction the aerospace sector. During the day-long session, participants focused on the respective roles of government and industry in funding and supporting basic research and applied research, the need for regulation to keep up with innovation and the importance of collaboration between industry and academia to fill the growing talent needs in this industry.



Leverage: Aerospace was released in August 2018 at an event hosted by the University of South Carolina. The event featured a follow-up conversation which sought to identify avenues through which to implement the recommendations in a way that would create economic opportunity for South Carolina's manufacturing sector.

Findings and Recommendations

- **Increase coordination between federal, state and local governments on aerospace infrastructure spending.** The United States is falling behind in infrastructure and is now ranked lower than many of its compatriots in airport efficiency. Many difficult technological problems must be solved if the aviation infrastructure needed for the future will provide the level of safety enjoyed today. Much of this stems from the disconnect of spending, as most airports are funded by state and local governments, and there is a lack of federal involvement.

Better coordination and additional government funding for basic research are needed to reclaim competitiveness in this sector.

- **Reform policy in a way that encourages and keeps up with the fast pace of innovation.** Aerospace has been a technologically driven sector from its inception. Policymakers must quickly address potential concerns around certain technological innovations, such as drones and space-based technology, in order to avoid the wealth of ethical and security concerns that could arise and regain the global lead in space exploration and travel.
- **Capitalize on America's energy opportunity to encourage innovation in the aerospace sector.** As the energy sector innovates and moves away from traditional fossil fuels, the aerospace sector has the opportunity to innovate its energy efficiency. This could include building upon innovations already being implemented in other countries, as well as in other sectors in the United States, including investment in areas from battery powered planes to solar-powered aircraft.
- **Increase the velocity of adoption of new materials to outpace global competition. It takes 10–20 years to take an aerospace material from design to deployment in the United States.** In order to maintain a competitive edge, computational techniques and methods must be applied to the qualification of new material systems through increased modeling and simulation. This will require an increased focus on science investment and commercialization and deliberate linkages between academic research and commercial deployment.
- **Build cybersecurity into aerospace technology and infrastructure.** Given the outstanding safety record of the aerospace industry and high levels of risk aversion, safety must evolve innovation, not after. As the flow of data and sharing of information becomes crucial to this sector and an increasing density of aircraft in the skies leads to a higher need for communication across the air and to the ground, cybersecurity will continue to become increasingly more important.
- **Encourage sharing of best practices between the aerospace and automotive sectors.** It is unlikely that cars and ground travel will ever be completely overshadowed by air transportation. Self-driving car models are now in development at multiple companies, with some already being tested for usability. Thus, it is necessary to think with a system-integration approach, where the two forms of travel and transport can work in conjunction for the betterment of society.
- **Promote partnerships between industry and academia to increase the talent pool.** The current promotion and tenure reward system discourages applied research, leaving a void to be filled by industry. But when viewed against the backdrop of decreasing federal research funding and shrinking R&D activity in many industries, the need for cooperation and collaboration to ensure innovation and motivation can be effectively translated into results and impact.
- **Redesign academic curricula at all levels to create a multidimensional workforce.** Creating a talent pool diverse in gender, ethnicity and skill will be essential to building competitiveness in the aerospace sector. Educators and employers

alike—as early as K-12 and up to mid-career professionals—must encourage the pursuit of opportunities in this growing industry. This might include everything from engineering competitions to opportunities through trade schools, classes offered by companies, online courses or community college offerings.

Cybersecurity

CO-CHAIRS

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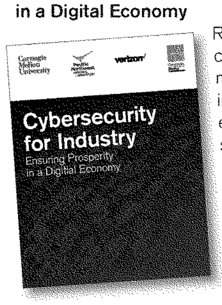
Cybersecurity for Industry: Ensuring Prosperity in a Digital Economy



Rapid advancement in cyber technology development is being fueled by industry modernization, e-commerce and consumer entertainment. The interconnectedness and openness made possible by the Internet and the broader digital ecosystem creates unparalleled value for society.

Advancements in computing, networking and communications technology permeate through every sector of the economy and are being made at a pace that is both breathtaking and unprecedented in human history. But these same qualities make securing today's cyber landscape extremely challenging. Technological advancement is outpacing security and will continue to do so unless we change the way we approach and implement cybersecurity strategies and practices.

With attribution of cyber-attacks becoming more difficult, and with these events happening at increasing rates, companies and organizations need a revised tool set to handle cyber-attacks quickly and effectively. And as adversarial AI becomes significantly more sophisticated in the next 3-5 years, the need to promote a cyber moon shot becomes increasingly more urgent. Cybersecurity is no longer a predominantly tech-related problem—due to the tremendous financial burden of cyber-attacks incurred as a consequence of disruption to operations, loss of data and cost of security among other concerns, cyber-attacks have become a risk management issue, while strong cyber defense/response can be a productivity enabler.

Despite the clear importance of cybersecurity in the current technological and political climate—and the threat cyber-attacks pose to critical infrastructure and intellectual property, and therefore to business operations and national security—resource constraints, both financial and human, are pervasive. Small- and medium-sized companies often face budgetary constraints that preclude them from affording the latest security technology. And firms of all sizes see talent shortages and knowledge gaps that leave them vulnerable to cyber risks and slow to recover from cyber-attacks.

These are just a few of the multidimensional security challenges companies in the United States face in an era marked by transformational innovation and the digitization of an exponential amount of data. These challenges, while difficult and numerous, are not insurmountable. They will, however, require collaboration on the parts of both the public and private sectors to improve America's mitigation, adaptability and resilience to the growing number of cyber threats from state and non-state actors

Initial Findings

Voluntary, industry-led cybersecurity standards, created in partnership with the government, are needed. While risk management frameworks and industry guidelines around cybersecurity exist, there is a need for industry-sponsored standards that define basic cybersecurity terms, and set security thresholds for products and systems. These standards could be used to benchmark security posture and create a competitive advantage for companies. The National Institute of Standards and Technology (NIST) could act as an umbrella infrastructure for these standards.

Security must be integrated into products and processes early on in the development cycle, rather than being considered an add-on component. As the pace of technological advancement accelerates at record speeds and products become increasingly connected through the proliferation of sensors and data, vulnerability to data theft and operational disruption increases. As the threat of cyber-attacks becomes more grave, products and processes must be designed with cyber resiliency in mind.

An overwhelming amount of data creates challenges with regard to credibility of cyber threats and ability to operationalize data. With the volume of useful, actionable information greater than ever before, a balance must be struck between information sharing required for legitimate policy interests and guarding private enterprise interests. Standardizing the gathering and valuation of cybersecurity data would improve security across all industries, but building trusted relationships is currently the best way to facilitate sharing of high-quality data on cybersecurity threats and attacks.

Cybersecurity must be transformed into a competitive advantage rather than a sunk cost by focusing on the confluence of risk, capabilities and resources. By treating cybersecurity as a pre-competitive issue, being proactive in addressing threats rather than reactive to attacks, and looking at cyber technologies and cybersecurity posture as valued capital rather than as a liability, companies can raise their security posture and insulate themselves from cyber threats. This requires more research into quantifiable risk that can enable a meaningful regulatory approach and insurance market that should in time be rewarded by the market.

All organizational levels, including company boards and C-suite leaders, must be engaged in cyber planning, response and recovery efforts. Cybersecurity is often considered the job of policy and IT experts. A shift in organizational culture across all organizational functions and levels to view cybersecurity as an issue of larger corporate relevance, rather than simply a technology problem, is necessary to improve companies' ability to protect against, respond to and recover from cyber-attacks.

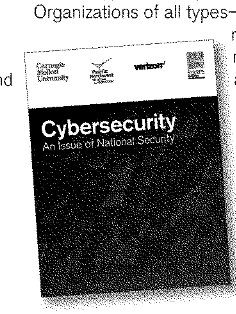
Industry and academia must work together to create a baseline curriculum to educate a knowledgeable, cyber-savvy workforce. It is vitally important for the United States to have an adequate, viable cybersecurity workforce with a consistent, baseline level of knowledge. Diversity and inclusion will be essential in order to meet the burgeoning needs in this field. Hands-on experience and mentorship programs would also help increase interest while combatting the slow pace of curriculum change. It would also be mutually beneficial for industry and academia to cross-pollinate and cycle practitioners and educators through both worlds.

Cybersecurity must be integrated into educational curricula outside traditional four-year universities and post-grad studies, including high schools and community colleges. The responsibility of educating on cybersecurity and computer science should not rest entirely on college and universities. College-level courses in cyber or computer science at the high school level would help expand the talent pool. Community colleges, with the support of industry executives, should also be considered a viable option for students and a viable recruitment pool for employers.

Cybersecurity: An Issue of National Security

The digitization of society, proliferation of data and increased connectedness of products and services—particularly in America's critical infrastructure sectors— have transformed the ways Americans live and organizations operate. Yet, the tremendous growth in the level of connectivity poses risks to U.S. global competitiveness as firewalls become the next frontline for battle in the United States. As a result, cybersecurity has become an issue of national security.

The United States is facing a steady increase in the volume, types and sophistication of cyber-attacks. Organizations of all types—including industry, government, academia and national laboratories—are assailed relentlessly by efforts from state and private entities to disrupt operations, steal information and increase their own competitiveness. These threats, which come in the form of traditional cyber-crime, military and political espionage, economic espionage and cyber warfare, carry considerable costs for the United States and the world. In fact, a study by Juniper Research suggests the annual cost of data breaches will reach $2.1 trillion globally by 2019, an increase of almost four times the estimated cost of breaches in 2015.[29]



Cyber-attacks are particularly concerning when it comes to the 16 critical infrastructure sectors as defined by the Department of Homeland Security[30] —each of which plays an integral role in America's economic and national security. A reliable energy grid, for example, is essential for any institution to operate. And while the U.S. Department of Energy currently

29 The Future of Cybercrime & Security, Juniper Research, March 25, 2017.

30 PPD-21 identifies 16 critical infrastructure sectors: chemicals; commercial facilities; critical manufacturing; dams; defense industrial base; emergency services; energy; financial services; food and agriculture; government facilities; healthcare and public health; information technology; nuclear reactors; materials and waste; sector-specific agencies; transportation systems; and water and wastewater systems. https://www.dhs.gov/critical-infrastructure-sectors.

has plans to improve preparedness, response and recovery capabilities, 90 percent of the energy grid is operated by private companies—requiring strong public and private partnerships to ensure these suppliers are resilient against and have the tools needed to respond quickly to potential cyber-attacks.[31]

The increasing sophistication of cyber-attacks poses a constant threat to critical infrastructure. And as the availability of networks is called into question every day, the economic viability of U.S. businesses and the freedoms Americans exercise daily are in jeopardy.

Initial Findings

Cybersecurity should be built into industry and government contracts to incentivize broader adoption. Cybersecurity must be better incentivized using new, innovative market mechanisms. This could include building security into procurement mechanisms or advancing how technologies are measured for security in order to institutionalize the adoption of security measures across the supply chain.

A unified, clear research agenda across industry and government is needed in the cybersecurity space. When it comes to cybersecurity research, there is no clear, community-defined research agenda, resulting in duplication of efforts and inefficient use of limited financial resources. A mechanism is needed to organize the research community and marshal appropriate stakeholders and topics to shape the research agenda.

Effort is needed to connect industry with laboratory and academic research to ensure knowledge transfer and reduce duplication. Discoverability of existing capabilities—both on the part of industry and the R&D community—is a significant challenge. Better coordination would reduce duplication of efforts—both within and across these communities—and help better align research priorities and commercial needs to scale up security solutions.

There must be a clearly-articulated federal model for cyber response to critical infrastructure attacks. While numerous government agencies are factoring cybersecurity into their programming and funding, there is minimal coordination across these programs. This would decrease duplication of efforts and improve resiliency and response capabilities in the face of cyber threats.

There is an opportunity at the state or regional level to capitalize on the patriotism, altruism and tech savviness of younger generations to create coalition(s) of cyber first-responders. Current recovery times from cyber-attacks are long and static, threatening American security and economic interests. The United States needs a coordinated first-response effort to further regional cyber protection and response. One potential home for this effort could be within the National Guard.

Globally-defined, security baselines are needed and must be informed by relevant stakeholders. Useful and practical security baselines would level the playing field and set basic expectations around how systems and networks can be deployed in recommended, secure configurations. Advances

31 Cybersecurity for Critical Energy Infrastructure, U.S. Department of Energy, 2018.

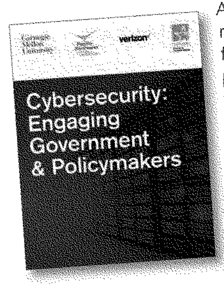
must be made through the product lifecycle to improve design, default and deployment, thereby building assurance around the resiliency of critical infrastructure to cyber-attacks and disruption.

Applying automated security monitoring to critical infrastructure sectors would significantly improve cyber defense. When applied to the observe-orient-decide-act loop, continual evaluation of security through artificial intelligence and machine learning can enable adversary detection, attribution and action prediction and improve response in a way that would reduce the asymmetric advantage of attackers and level the cyber defense playing field for critical infrastructure providers.

Cybersecurity must be integrated into the academic curricula of related topics. While training cybersecurity professionals is a valuable endeavor, cybersecurity must be a key educational component for computer scientists, engineers and other professions in which security is a foundational concern. This will increase the pool of professionals with relevant and applicable cybersecurity skills across the most critical areas of need and ensure that future engineers across all disciplines are able to design and build secure systems.

Barriers prohibiting practitioners to serve as educators must be reduced. While there are significant challenges around a mismatch between supply and demand of cybersecurity professionals, academia faces the compounding challenge of a lack of educators to train the workforce of tomorrow. A strategic effort on the part of industry and academia is needed to fill this gap.

Cybersecurity: Engaging Government & Policymakers



As computing power rapidly increases, the U.S. faces the challenge of protecting the latest technology from the increasing threat of cyber-attacks. This task will only become more difficult given the rising number of devices connected to the electric grid as smart homes and buildings become the norm. Although the United States is progressively making cybersecurity a higher priority for the nation, there is still much work to be done to secure critical infrastructure.

Already at a disadvantage in comparison to its adversaries, U.S. policymakers must act to build resilience to the increasing threat and occurrence of cyber-attacks. Without a single group or entity within government designated to take charge in the face of a large-scale attack, adversaries are able to maximize their already asymmetric advantage and exploit weaknesses in U.S. response capabilities. And while agencies like the Department of Energy have taken critical steps to protect America's energy infrastructure, coordination and effective communication with Congress is necessary to ensure efficient use of the limited resources available to support nationwide cybersecurity.

Simultaneously, the challenges posed by the increasing cyber threat from state and non-state actors continue to outpace the size of the workforce equipped with the skills to mitigate the growing risk. While programs exist throughout the federal government, including the National Science Foundation's CyberCorps®: Scholarship for Service, a scholarship program to recruit and train the next generation of information technology professionals, industry control system security professionals and security managers, these efforts must be amplified in order to keep pace with the growing need for cybersecurity professionals.

Together, policymakers across all federal agencies must address the growing threat of cyberattack to the United States. Coordination and collaboration, are essential if the United States is to secure against the threat of attack, enhance cyber resilience, strengthen the cyber workforce and boost the awareness needed to remain competitive.

There must be a clear, practical model for cyber response that identifies roles and responsibilities of the public and private sectors. Numerous federal agencies currently have jurisdiction over different aspects of cybersecurity, leaving uncertainty as to where responsibilities lie in the wake of an attack. Similarly, there is a lack of clarity on the part of industry as to the requirements. Clear leadership in the cybersecurity space would help the United States maintain its competitive advantage by thwarting cyber threats.

Small- and medium-sized businesses often lack access to the knowledge and resources needed to maintain an appropriate level of cybersecurity. Much of industry is below the cyber "poverty line", meaning they do not have access to the resources needed for basic cyber hygiene, much less defending against nation-states. These businesses can serve as a gateway into larger organizations for attackers. Tools and guidance for small and medium businesses would improve supply chain cybersecurity writ large.

Tools for assessing the performance, benefit and risk associated with cyber tools must be developed. Independent consumer reports tests or assurance programs that correlate to improved cybersecurity posture would improve supply chain security and enable the uptake of proven security technologies.

The current talent pool cannot meet the rising demand for cybersecurity workers. Without intervention, the United States will experience a debilitating lack of talent to fill cybersecurity needs essential for maintaining our competitive advantage globally. Tools must be developed to train cybersecurity professionals at all levels—from first response practitioners to experts.

Cybersecurity must be incentivized as a risk management issue to raise the overall security posture of American industry and critical infrastructure. When cybersecurity is perceived by businesses as cost, decisions are made from a cost-benefit perspective rather than a risk management vantage point. This becomes a challenge as cybersecurity risks span beyond the source of the incident. Cyber protections and processes must be valued as capital rather than cost.

Security must be built into products and systems from the very earliest stages of development. The pace of innovation and technology uptake by the general public has historically been driven by convenience and functionality as opposed to security. This creates a situation where technology is used long before its security implications are understood. Creating a basic blueprint that provides a succinct path for security-enabled technologies to transition from research to market will minimize stranded research and increase the overall security posture of the United States by facilitating the introduction of new, more secure products to the market.

About the Council on Competitiveness

For more than three decades, the Council on Competitiveness (Council) has championed a competitiveness agenda for the United States to attract investment and talent, and spur the commercialization of new ideas.

While the players may have changed since its founding in 1986, the mission remains as vital as ever—to enhance U.S. productivity and raise the standard of living for all Americans.

The members of the Council—CEOs, university presidents, labor leaders and national lab directors—represent a powerful, nonpartisan voice that sets aside politics and seeks results. By providing real-world perspective to Washington policymakers, the Council's private sector network makes an impact on decision-making across a broad spectrum of issues from the cutting-edge of science and technology, to the democratization of innovation, to the shift from energy weakness to strength that supports the growing renaissance in U.S. manufacturing.

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

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APPENDIX A

A National Agenda for Cybersecurity

A national cyber agenda must ensure the United States has the infrastructure, technology and talent needed to build resilience to cyber-attacks, along with the ability to respond and recover in the event of such attacks.

The interconnectedness and openness made possible by the Internet and the broader digital ecosystem create unparalleled value for society. The architects of the Internet could not know, however, that it would reach the breadth and scope seen today. Throughout human history, technological advancement has outpaced security. While this is unlikely to change, America's ability to remain resilient in the face of increasing cyber threats will require a shift in the understanding of—and dynamic between—innovation and security. The evolution to a new way of thinking that focuses on deliberate, risk-informed trade-offs will be essential.

What follows are a series of concrete, actionable recommendations cutting across the public and private sectors that, taken together, will strengthen U.S. cyber defenses and ensure greater resilience in the face of growing and malicious cyber threats.

Secure America's Critical Assets and Infrastructure Against Cyber-attacks

With the average cost of a data breach in the United States at an all-time high of $7.91 million and over 1,300 significant breaches in the last year, malicious cyber activity in the United States is a substantial threat to America's economic and national security.[32] The increasing sophistication of cyber-attacks poses a constant threat to critical infrastructure. And as the availability of networks is called into question every day, the economic viability of U.S. businesses and the freedoms Americans exercise daily are in jeopardy.

1. Curtail the foreign acquisition by hostile actors of American cybersecurity assets to better manage risk. Regional powers have a growing potential to use purchased cyber tools to conduct catastrophic attacks on U.S. critical infrastructure.[33] While cyber threats from state and non-state actors come in many forms, including cyber-crime and military and political espionage, the acquisition by hostile foreign governments of U.S. cyber assets constitutes a significant security risk for the United States.

Recommendations

1.1. Require under the new authorities of the Foreign Investment Risk Review Modernization Act (FIRRMA) in the National Defense Authorization Act for Fiscal Year 2019 that the Committee on Foreign Investment in the United States (CFIUS) conduct full reviews and regulatory approval for any foreign investment or ownership interest in American advanced cybersecurity startups, joint ventures or acquisitions.

32 *2018 Cost of a Data Breach Study*, Ponemon Institute, July 2018.

33 *Task Force on Cyber Deterrence*, Department of Defense Defense Science Board, February 2017.

1.2. Require all U.S. securities and SEC-registered securities and investment funds of any size to provide the U.S. Department of the Treasury and the FBI full transparency on sources of investment capital and intellectual property, and limit partners from countries deemed high-risk or sanctioned by the Treasury Department.

1.3. Expand the authority of the Bayh-Dole Act and federal tech transfer act to prevent the licensing of U.S. cyber technology developed with federal funding to foreign countries deemed high risk.

2. Leverage public and private sector purchasing power to ensure cybersecurity protections are upfront requirements throughout the value chain. While DoD contractors and subcontractors are required to meet certain security protocols, there is no universal clause across federal procurement contracts. And, industry largely lacks a consistent approach to applying best practices for security design, development and deployment of Internet-connected devices.

Recommendations

2.1. Extend Defense Federal Acquisition Regulation Supplement DFAR 252.204-7012 language mandating adequate security to all government agencies.

2.2. Call on Congress to take immediate action on the Internet of Things ('IoT') Cybersecurity Improvement Act of 2017, requiring the inclusion of specific cybersecurity protections in procurement contracts with all federal and state agencies for Internet-connected devices.

2.3. Incentivize vendors' awareness and adoption of security best practices utilizing industry purchasing power.

2.4. Promote greater uptake and use of existing cybersecurity standards to increase supply chain security.

3. Establish a means of coordinating cyber R&D investments and research agendas. When it comes to cybersecurity research, there is no community-defined research agenda, resulting in duplication of efforts and inefficient use of limited financial and human resources.

Recommendations

3.1. Establish the National Cybersecurity R&D Initiative, chaired by the White House Science Advisor, to identify challenges, solicit industry input, define priorities and, on an ongoing basis, coordinate government investment to optimize talent and resources and avoid duplication of efforts.

3.2. Convene a Basic Research Needs working group including leaders from the public and private sectors to define a set of research priorities to address the technology R&D challenges and Science Grand Challenges that, if solved, will strengthen U.S. cybersecurity capability.

3.3. Create data-driven processes to develop specific cybersecurity countermeasures unique to sectors and sub-sectors, and disseminate these processes through Information Sharing and Analysis Centers and Community Emergency Response Teams to mitigate the risk of cyber incidents.

4. Develop, upgrade and deploy cybersecurity technology to enhance America's resilience to cyber-attacks. The pace of technological advancement is accelerating at record speeds, increasing vulnerability to data theft and operational disruption increases. As the threat of cyber-attacks becomes more grave, products and processes must be designed to meet basic security standards.

Recommendations

4.1. Require that all new technology applied to the electric grid meet industry standards to ensure basic cybersecurity.

4.2. Expand funding and private sector engagement for testbeds for the creation and adoption of new cybersecurity technologies such as Digital Manufacturing Design and Innovation Institute (DMDII) Cyber Hub for Manufacturing and the Army Cyber-research Analytics Laboratory.

4.3. Expand the NIST cybersecurity framework to better guide secure development of IoT, operational technology (OT) and information technology (IT) platforms and technologies as a means to bolster private industry certification programs.

Strengthen America's Cyber Response and Recovery Capabilities

According to the latest data, in the United States, the average time required to identify a data breach incident is 201 days, while the average amount of time to contain a breach is 52 days.[34] America's ability to detect, withstand and recover from cyber events that disrupt the economy and society in a quick and coordinated manner is essential for the nation's security and competitiveness.[35]

5. Enhance coordination across departments and agencies at the federal and state levels responsible, with the goal to improve resiliency and response to cyber threats. While numerous federal agencies are factoring cybersecurity into their programming and funding, there is minimal coordination across departments.

Recommendations

5.1. The administration should reinstate and empower a White House cybersecurity czar to oversee a government-wide interagency task force to develop and implement, within 180 days, a coordinated cyber defense strategy that includes mechanisms for owners and operators of critical infrastructure to more easily share appropriate data.

5.2. Governors should convene state and local representatives from across the public and private sectors to develop statewide cyber-attack prevention and response strategies.

34 "IBM Study: Hidden Costs of Data Breaches Increase Expenses for Businesses," PRNewswire, IBM Security, July 11, 2018.

35 "Protecting Small Businesses from Cyber Attacks: the Cybersecurity Insurance Option", Testimony of Robert Luft, Owner, Surefire Innovations, National Small Business Association, July 26, 2017.

5.3. Convene biannual meetings of the private sector chairpersons of federal government advisory committees and external boards to share agency priorities, best practices and identify areas to strengthen interagency collaboration.

6. Develop agile, mobile and technically trained state and/or regional coalitions of cyber first-responders. Current recovery times from cyber-attacks are long and protracted, threatening American security and economic interests. With the average cost of a data breach in the United States at an all-time high of $7.91 million,[36] efficient incident response is critical and current assets are insufficient.

Recommendations

6.1. Institute state Cyber Protection Teams through the National Guard Bureaus and tactical analysis groups.

6.2. Governors and state legislators must provide funding and reduce legal and liability barriers to resources acting in state capacity.

6.3. Expand to additional states existing programs[37] to provide veterans with access to cybersecurity training opportunities and resources to help veterans enter the cybersecurity workforce.

6.4. Establish and fund, at the state level, "civilian reserve cyber corps" comprising volunteers from private industry security and IT professionals to be deployed in the event of a regional cyber incident.

6.5. Create a tiered technology approach to cyber that enables technically-trained cyber experts—people who are experts in using tools but that don't require advanced degrees—to obtain the technical skills needed to act in this capacity.

7. Expand access to cyber resources for small and medium-sized companies. Small businesses—those with fewer than 100 workers—represent more than 98 percent of total businesses in the United States.[38] In fact, 58 percent of data breach victims are small businesses.[39] Small businesses estimated their average cost for incidents in the last 12 months to be $34,604.[40]

Recommendations

7.1. Sustain funding for the Manufacturing Extension Partnership (MEP) National Network and expand resources available for cybersecurity tools and training and certification such as the NIST MEP Cybersecurity Assessment Tool.

7.2. State and metropolitan Small Business Administrations should establish cybersecurity training initiatives in partnership with Workforce Development Boards to reach a broad array of small and medium-sized businesses below the cyber poverty line.

7.3 Expand federal and state outreach to small and medium-sized businesses to increase knowledge of existing resources, including top resources identified by the DHS U.S. Computer Emergency Readiness Team (US-CERT).

36 *2018 Cost of a Data Breach Study: Global Overview*, Ponemon Institute, July 2018.

37 Cyber Virginia: Cyber Veterans Initiative, The Commonwealth of Virginia, July 2017.

38 *Annual Survey of Entrepreneurs*, U.S. Census Bureau, 2016.

39 *2018 Data Breach Investigations Report*, Verizon, 2018.

40 *2018 HISCOX Small Business Cyber Risk Report*, Hiscox Inc, 2018.

8. Engage corporate leadership in the development of procedures necessary to plan for, respond to and recover from cyber incidents. Cybersecurity has become an urgent concern for companies of all sizes and across all industries. Cyber threats pose significant risks to economic security and competitiveness and have become increasingly costly in terms of detection and response.

Recommendations

8.1. Corporate cybersecurity leads should report directly to executive team members and align responsibilities with risk management strategies.

8.2. Companies should embrace the Securities and Exchange Commission Guidance on Public Company Cybersecurity Disclosures[41] and take all required actions to inform investors of material cyber risks and incidents in a timely fashion.

Develop and Deploy a 21st Century Cyber Workforce

Further adding to the growing risk of cyber threats to American prosperity, the world is on pace to reach a cybersecurity workforce gap of 1.8 million by 2022.[42] It is vitally important that the United States have an adequate cybersecurity workforce to secure the nation's critical infrastructure; respond to the ever-expanding cyber threat; and equip businesses of all sizes and governments at all levels with the talent to meet the next generation of cyber challenges.

9. Expand and upskill the cybersecurity workforce to meet the complex and growing cyber threat. The cybersecurity field faces a constant shortage of practitioners, with approximately 350,000 current cybersecurity openings unfilled, according to CyberSeek, a project supported by the National Initiative for Cybersecurity Education (NICE).

Recommendations

9.1. Ensure NSF funding for the CyberCorps®: Scholarship for Service (SFS) program meets the growing demand.

9.2. The National Science Foundation should expand and expedite the implementation of the Community College Cyber Pilot Program (C3P) under the CyberCorps® SFS program.

9.3. Congress should take immediate action to pass S. 754, Cyber Scholarship Opportunities Act of 2017 to permanently extend support for cybersecurity education in primary and secondary schools.

9.4 Expand cybersecurity awareness programs in secondary schools to increase interest and awareness of students from diverse backgrounds regarding career opportunities in the cybersecurity field.

41 Commission Statement and Guidance on Public Company Cybersecurity Disclosures, 2018.

42 *2017 Global Information Security Workforce Study*, Frost & Sullivan, 2017.

10. Reform curricula at the nations's colleges and universities to better meet the demand for cyber-savvy students and workers. The race to respond to cyber workforce needs has led to inconsistency in program quality and stove piping of expertise. The ability of academia, industry and government to address these challenges while meeting the growing workforce demand will be a key driver of American competitiveness.

Recommendations

10.1. Expand the number of colleges and universities with programs and credentials that meet the criteria required for designation as National Centers of Academic Excellence in Cyber Operations or Cyber Defense by the National Security Agency and the DHS.

10.2. Embed cybersecurity concepts into a broad range of existing degree programs at the university level.

11. Break down legal and organizational barriers prohibiting or limiting cybersecurity practitioners from serving as educators. While there are significant challenges around a mismatch between supply and demand of cybersecurity professionals, academia faces a compounding challenges of a lack of educators to train the workforce of tomorrow.

Recommendations

11.1. States and educational institutions must reduce barriers to allow cybersecurity practitioners to serve as professors of practice.

11.2. Establish industry-academia-national laboratory exchange programs to facilitate cross-pollination between cyber experts and practitioners.

Boost Cyber Awareness Among Policymakers and the Public

Human error is one of the most significant challenges when it comes to protecting against cyber-attacks. In fact, 90 percent of cyber incidents are human-enabled,[43] while as many as 24 percent of attacks may be due to employee actions or mistakes. [44]

12. Increase the awareness and understanding of cybersecurity issues among members of Congress and their staffers. With at least 36 states, D.C. and Puerto Rico having introduced and/or considered more than 265 bills or resolutions related to cybersecurity[45] and as many as 12 committees holding jurisdiction over various departments, agencies and programs addressing cyber issues, all policymakers on Capitol Hill must understand the technology and implications of cyber threats.

Recommendation

12.1. Members in the House of Representatives and Senate should reinvigorate the bipartisan House and Senate Cyber Caucuses, which have been largely dormant in recent years, to provide members of Congress and their staffers with access to experts in the field.

43 Shifting the Human Factors Paradigm in Cybersecurity, Calvin Nobles, Ph.D., March 15, 2018.

44 2016 Data Security Incident Response Report, BakerHostetler, 2016.

45 Cybersecurity Legislation 2018, National Conference of State Legislatures, May 18, 2018.

13. Increase the cyber awareness of the general public. An ever-evolving number of cyber threats target what is, in many ways, the weak link in the U.S. cyber ecosystem—the general public. Spam, phishing, spyware, malware, trojan horses and a litany of targeted consumer attacks can ruin personal financial security and be a gateway to a broader attack with the consumer as the entry point. Cyber savviness is no longer a luxury, but a necessity for all Americans.

Recommendations

13.1. Fund, develop and implement a major national cyber-awareness campaign, that builds on existing efforts, to increase the general public's awareness and capability to prepare for and respond to cyber threats.

13.2. Call on local economic development authorities to put in place programs that encourage cybersecurity education at the K-12 level.

13.3. Implement and enforce basic cybersecurity protocols throughout industry, government and academia including patching, multi-factor authentication and identity management as standard business practices.

APPENDIX B

Innovate America National Innovation Agenda

Talent

Build a **National Innovation Education Strategy** for a diverse, innovative and technically-trained workforce

- Establish tax-deductible private-sector "Invest in the Future" scholarships for American S&E undergraduates
- Empower young American innovators by creating 5,000 new portable graduate fellowships funded by federal R&D agencies
- Expand university-based Professional Science Masters and traineeships to all state university systems
- Reform immigration to attract the best and brightest S&E students from around the world and provide work permits to foreign S&E graduates of U.S. institutions

Catalyze the **Next Generation of American Innovators**

- Stimulate creative thinking and innovation skills through problem-based learning in K-12, community colleges and universities
- Create innovation learning opportunities for students to bridge the gap between research and application
- Establish innovation curricula for entrepreneurs and small business managers

Empower **Workers to Succeed in the Global Economy**

- Stimulate workforce flexibility and skills through lifelong learning opportunities
- Accelerate portability of healthcare and pension benefits
- Align federal and state skills needs more tightly to training resources
- Expand assistance to those dislocated by technology and trade

Investment

Revitalize **Frontier and Multidisciplinary Research**

- Stimulate high-risk research through "Innovation Acceleration" grants that re-allocate 3 percent of agency R&D budgets
- Restore DoD's historic commitment to basic research by directing 20 percent of the S&T budget to long-term research
- Intensify support for physical sciences and engineering to achieve a robust national R&D portfolio
- Enact a permanent, restructured R&E tax credit and extend the credit to research conducted in university-industry consortia

Energize the **Entrepreneurial Economy**

- Build 10 Innovation Hot Spots over the next 5 years to capitalize on regional assets and leverage public-private investments
- Designate a lead agency and an inter-agency council to coordinate federal economic development policies and programs to accelerate innovation-based growth
- Increase the availability of early-stage risk capital with tax incentives, expanded angel networks, and state and private seed capital funds

Reinforce **Risk-Taking and Long-Term Investment**

- Align private-sector incentives and compensation structures to reward long-term value creation
- Create safe-harbor provisions to promote voluntary disclosure of intangible assets
- Reduce the cost of tort litigation from 2 percent to 1 percent of GDP
- Convene a Financial Markets Intermediary Committee to evaluate the impact of new regulations on risk-taking

Infrastructure

Create **National Consensus for Innovation Growth Strategies**

- Enact a federal innovation strategy through the Executive Office of the President
- Catalyze national and regional alliances to implement innovation policies and innovation-led growth
- Develop new metrics to understand and manage innovation more effectively
- Establish National Innovation prizes to recognize excellence in innovation performance

Create a **21st Century Intellectual Property Regime**

- Build quality in all phases of the patent process
- Leverage patent databases into innovation tools
- Create best practices for collaborative standards setting

Strengthen **America's Manufacturing Capacity**

- Create centers for production excellence including shared facilities and consortia
- Foster development of industry-led standards for interoperable manufacturing and logistics
- Create Innovation Extension Centers to enable SMEs to become first-tier manufacturing partners
- Expand industry-led roadmaps for R&D priorities

Build **21st Century Innovation Infrastructures – the health care test bed**

- Expand electronic health reporting
- Establish and promote standards for an integrated health data system
- Establish pilot programs for international electronic exchanges on healthcare research and delivery
- Expand use of performance-based purchasing agreements

APPENDIX C

Drive. Private Sector Demand for Sustainable Energy Solutions Recommendations

Create the Foundation for Success

Global Prerequisites

Recommendation: Expand Trade and Global Growth

- Remove tariffs and non-tariff barriers for sustainable energy products and services while not creating a dual track for preferential trade liberalization
- Assure intellectual property rights (IPR) for all industrial products and services, copyrights and sustainable energy solutions

Recommendation: Take the Lead in Copenhagen

- Commit to reduce U.S. emissions on a set timetable
- Promote reduction targets for all major emitters

Recommendation: Collaborate with Developing Nations in Reducing Emissions

- Provide financial and technical support

American Prerequisites

Recommendation: Clarify Policies and Inform the Public

- Clarify and coordinate energy and environmental policies across federal agencies
- Take a "systems approach" to policy and funding decisions
- Increase America's energy knowledge
- Disclose energy and carbon data for buildings and products

Setting the Bar for Energy Efficiency

Recommendation: Reward Efficiency

- Provide tax credits and federal financing for home efficiency improvements
- Provide tax credits to accelerate the turnover to advanced technology vehicles
- Make a step change in vehicle efficiency standards and vehicle miles traveled
- Peg appliance standards to best-in-class
- Allow utilities to profit from energy efficiency so customers receive incentives

Assuring Access to Clean and Competitive Energy

Recommendation: Use it All and Price it Right

- Rationalize federal and state regulatory policies
- Drive diversification to low-carbon energy sources
- Assure renewables access to the grid
- Expedite nuclear power plant approvals and re-commissioning
- Eliminate regulatory uncertainty for nuclear waste
- Expedite construction of carbon capture and storage facilities
- Establish a price floor for gasoline
- Link the gasoline tax to CAFÉ standards
- Price carbon emissions

Jumpstarting Energy Infrastructure and Manufacturing Investments

Recommendation: Capitalize Growth and Make It Here

- Reduce the corporate tax rate
- Generate a revenue pool for infrastructure financing
- Enable high-risk, high-return energy projects
- Invest in nuclear industry expansion
- Provide a steady stream of manufacturing and job creation financing
- Designate Clean Energy Technology Manufacturing Development Zones
- Establish Clean Energy Manufacturing Centers of Excellence
- Provide federal financial investment in initial manufacturing facilities for clean energy technologies
- Incentivize production retooling and efficiency for clean energy technology production
- Enhance industrial access to HPC resources

Clearing Obstacles to a National Transmission Superhighway

Recommendation: Build it Fast and Smart

- Set national criteria for transmission siting
- Recover transmission costs on a regional basis
- Develop standards for device interoperability and security

Spawning Technological Breakthroughs and Entrepreneurship

Recommendation: Discover the Future and Break the Technology Barriers

- Provide a steady, robust stream of R&D funding
- Launch clean energy research consortia for enabling energy technologies
- Fast-track technology demonstrations and pilots for CCS and energy storage
- Fast-track demonstrations of new nuclear reactors

Mobilizing a World-Class Energy Workforce

Recommendation: Bridge the Skills Gap and Build the Talent

- Boost funding for workforce training in clean technology
- Develop and nurture world-class energy researchers and educators
- Provide full scholarships for energy-related education
- Make worker training benefits portable
- Harness global talent by amending U.S. immigration laws
- Cultivate youth interest in clean energy and environmentally-sound industry
- Give private industry a stake in creating a pipeline of workers
- Bridge funding gaps for community colleges
- Galvanize local coalitions

APPENDIX D

Make: Five Challenges and Solutions to Make an American Manufacturing Movement

Priorities

The priority recommendations from the five challenges are:

1. Congress should permanently replace the current world-wide double taxation system with a territorial tax system to facilitate the repatriation of earnings and restructure the corporate tax code to increase investment, stimulate production at scale and neutralize sovereign tax incentive investment packages.
2. Congress, the administration and industry should intensify efforts to support the President's goal to double exports from $1.8 to $3.6 trillion and reduce the trade deficit by more than 50 percent.
3. Federal, state and local governments along with high-schools, universities, community colleges, national laboratories and industry should prioritize Career and Technical Education (CTE) programs and push for greater integration of community colleges in the innovation pipeline.
4. Congress and the administration should leverage R&D investments across the federal research enterprise to solve challenges in sustainable smart manufacturing systems and to ensure a dynamic discovery and innovation pipeline.
5. Congress and the administration should drive the private sector to develop and utilize all sources of energy on a market basis while enforcing efficiency standards to ensure a sustainable supply of energy to manufacturers.

CHALLENGE

Fueling the Innovation and Production Economy from Start-up to Scale-up.

SOLUTION

Enact fiscal reform, transform tax laws and reduce regulatory and other structural costs and create jobs.

1. Congress should require agencies to begin reducing the costs and burdens of current and proposed regulations.
2. Congress should immediately reform section 404 of the Sarbanes-Oxley Act to increase entrepreneurs' access to U.S. public capital markets and grow new companies.
3. Congress should reduce the costs of tort litigation from the current level of almost two percent of GDP—some $248 billion—down to one percent by 2020.
4. Congress and the administration must take action on fiscal reform to achieve $4 trillion in debt reductions by 2021.

CHALLENGE

Expanding U.S. Exports, Reducing the Trade Deficit, Increasing Market Access and Responding to Foreign Governments Protecting Domestic Producers.

SOLUTION

Utilize multilateral fora, forge new agreements, advance IP protection, standards and export control regimes to grow high-value investment and increase exports.

1. Industry CEOs and government leaders should elevate and advance U.S. technical standards and the voluntary consensus standards-setting process.
2. Congress and the administration should ensure the President's Export Control Reform Initiative is completed by the end of 2012 and push for improved foreign export control systems.
3. Focus on actions to encourage China to make permanent the special intellectual property rights campaign it ran from October 2010 to June 2011.

CHALLENGE

Harnessing the Power and Potential of American Talent to Win the Future Skills Race.

SOLUTION

Prepare the next generation of innovators, researchers and skilled workers.

1. Congress should implement immigration reform to ensure the world's brightest talent innovate and create opportunities in the United States.
2. Congress, states, academia, industry and national laboratories should renew efforts to expand STEM education and create opportunities to integrate into the workplace.
3. The Small Business Administration (SBA) should create a program modeled after the SCORE program for retired business executives to mentor and counsel entrepreneurs.
4. Industry and labor should develop state-of-the-art apprenticeship programs for 21st century manufacturing.
5. The administration should create a Veterans in Manufacturing Program to create opportunities for America's soldiers.
6. Academia, industry and government should launch the American Explorers Initiative to send more Americans abroad to study, perform research and work in global businesses.
7. Congress should create opportunities and incentives for older Americans to remain vibrant contributors in the workforce.

CHALLENGE

Achieving Next-Generation Productivity through Smart Innovation and Manufacturing.

SOLUTION

Create national advanced manufacturing clusters, networks and partnerships, prioritize R&D investments, deploy new tools, technologies and facilities, and accelerate commercialization of novel products and services.

1. Congress, the administration, industry, academia and labor should develop partnerships to create a national network of advanced manufacturing clusters and smart factory ecosystems.
2. Congress, the administration, national laboratories and universities should advance the U.S. manufacturing sector's use of computational modeling and simulation and move the nation's High Performance Computing capabilities toward Exascale.
3. The U.S. Department of Commerce through the Economic Development Administration, in partnership with the Council on Competitiveness should expand the Midwest Project for SME–OEM Use of Modeling and Simulation through the National Digital Engineering and Manufacturing Consortium (NDEMC).
4. Accelerate innovation from universities and national laboratories by facilitating greater sharing of intellectual property and incentivizing commercialization.

CHALLENGE

Creating Competitive Advantage through Next Generation Supply Networks and Advanced Logistics.

SOLUTION

Develop and deploy smart, sustainable and resilient energy, transportation, production and cyber infrastructures.

1. Congress should increase the number of public-private infrastructure partnerships and explore opportunities to privatize large infrastructure projects.
2. Congress should authorize the Export-Import Bank to fund domestic infrastructure projects.
3. Congress should develop and implement a national strategy to reduce overall energy demand by rewarding efficiency and improving transmission infrastructure.
4. Congress and the administration should create a Joint Cyber Command to improve cyber infrastructure and protect traditional defense, commercial and consumer interests.

APPENDIX E

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Cybersecurity: Engaging Government & Policymakers

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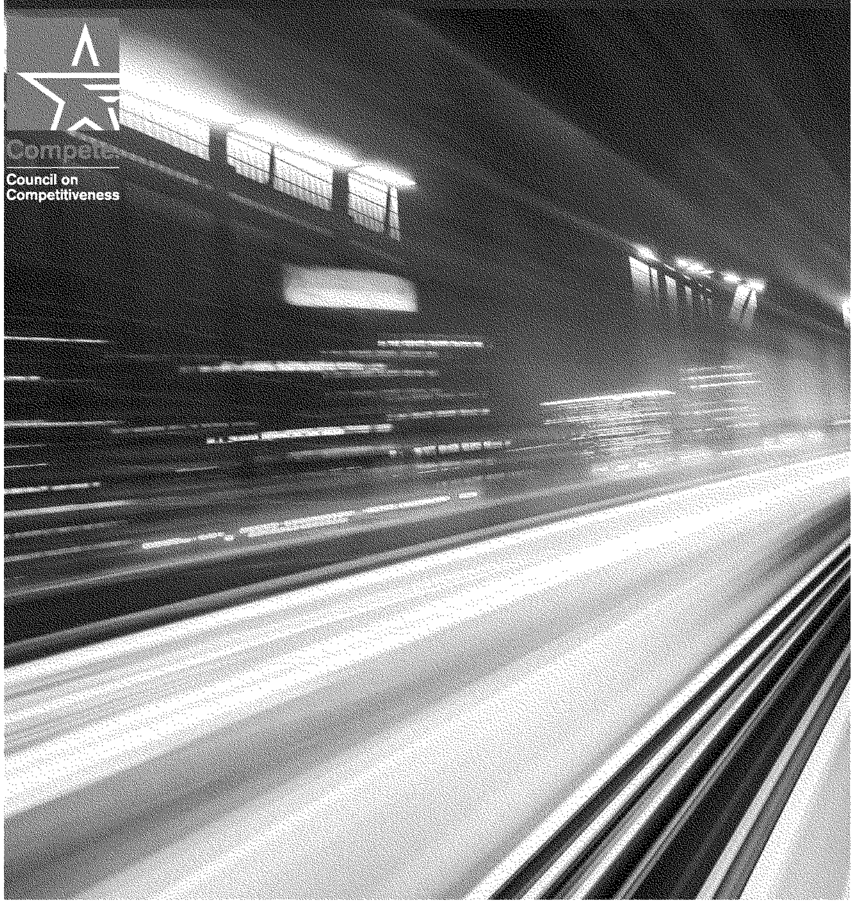

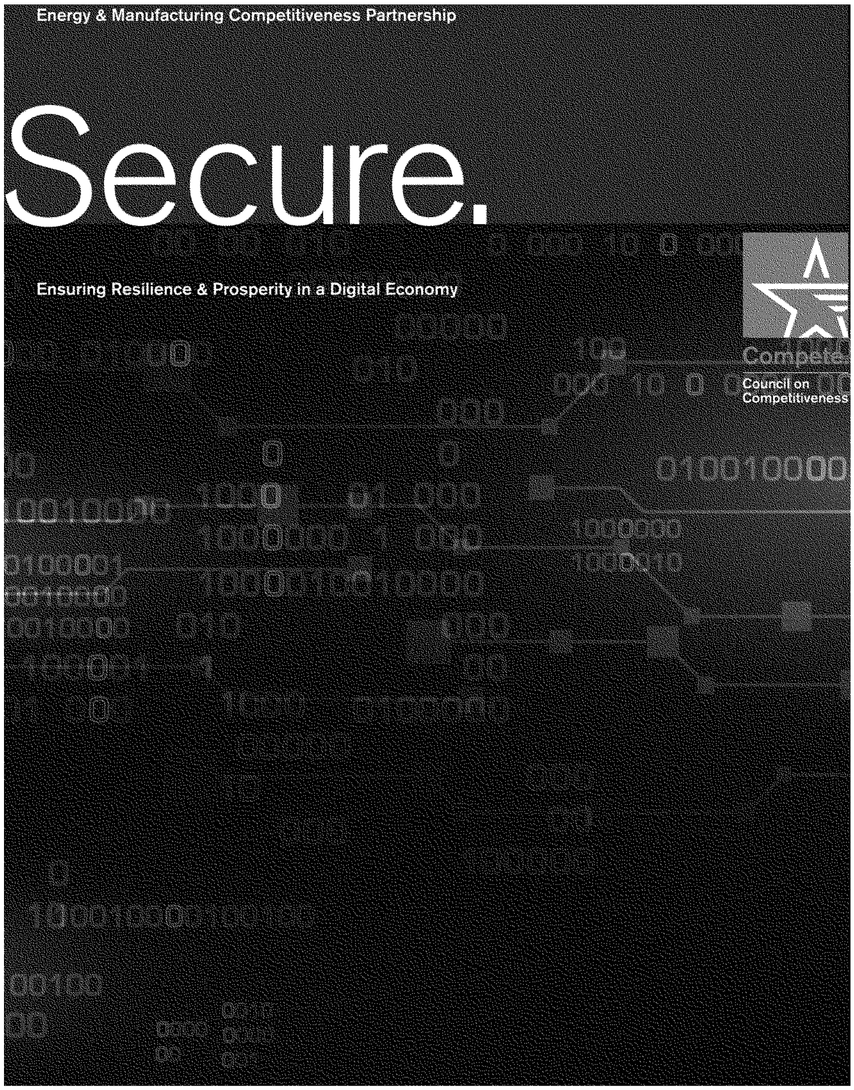
Energy & Manufacturing Competitiveness Partnership
Secure.
Ensuring Resilience & Prosperity in a Digital Economy
Council on
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Secure. Ensuring Resilience & Prosperity in a Digital Economy

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Table of Contents

Letter from the Co-Chairs

Three years ago, the Council on Competitiveness (Council) launched the Energy and Manufacturing Competitiveness Partnership (EMCP) to better understand the policy implications of the tectonic shifts taking place in the energy and manufacturing sectors. The EMCP conducted six sector studies on the topics of: water and manufacturing; advanced materials; bioscience; agricultural and consumer water use; energy and aerospace.

These dialogues were designed to elicit common themes, findings and recommendations across the various sectors. Coming to the forefront very early on was the realization that the proliferation of data and increased connectedness of products and services was creating a new set of challenges and opportunities around securing information from the threat of cyber-attacks.

Cybersecurity is crucial to economic and national security and national competitiveness. And cyber threats to America's critical infrastructure are daunting. In its quadrennial *Global Trends* analysis, the National Intelligence Council warns that protecting critical infrastructure from cyber-attacks, including private sector networks and infrastructure such as crucial energy systems, will become an increasingly important national security challenge.

Securing energy infrastructure, in particular, from cyber threats is fundamental to U.S. economic and homeland security because of its crucial intersection with other critical infrastructures—from power and manufacturing to transportation and healthcare—that rely on energy to operate. In short, the United States needs new models for valuation of cybersecurity, including a commitment that resilience be baked into the DNA of organizations with robust processes, secure and responsive systems, and well-trained people.

Secure: Ensuring Resilience & Prosperity in a Digital Economy encapsulates the collective wisdom of more than 150 experts in the cyber field representing industry, academia, labor, national laboratories and government, and puts forth a national agenda for cybersecurity that, if enacted, would strengthen U.S. capabilities in this critical area. We look forward to working with all stakeholders to better prepare for, prevent and respond to cyber threats, and to ensure greater U.S. national and economic security.

Sincerely,

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Executive Summary

The interconnectedness and openness made possible by the Internet and the broader digital ecosystem create unparalleled value for society. The architects of the Internet could not know, however, that it would reach the breadth and scope seen today.

In 2018, the U.S. Department of Homeland Security (DHS) declared that cyber weapons and sophisticated hacking pose a greater threat to the United States than the risk of physical attacks. With the U.S. economy losing between $57 billion and $109 billion per year to malicious cyber activity,1 it is clear that in order to remain secure and competitive, the United States needs a comprehensive national policy agenda in the cybersecurity space.

In recognition of the growing importance of cybersecurity to America's economic and national security, the Council on Competitiveness in 2018 launched a three-dialogue series on increasing the resilience of the nation's critical infrastructure, intellectual property and industrial operations against cyber-attack. The series, co-chaired by Dr. Steven Ashby, director of Pacific Northwest National Laboratory, Mr. George Fischer, senior vice president and group president of Verizon Enterprise Solutions, and Dr. Farnam Jahanian, president of Carnegie Mellon University, focused on the security and economic challenges posed by the increasing cyber threat and sought to identify mechanisms for building resilience in the new battlefield of digital warfare.

The cybersecurity initiative engaged more than 150 experts and consisted of three dialogues, each of which sought to identify the challenges and opportunities in distinct sectors of the economy. The first dialogue, hosted by Verizon in New Jersey in February 2018, examined the role of the private sector in U.S. critical infrastructure. The discussion made clear that despite the clear importance of cybersecurity in the current technological and political climate—and the threat cyber-attacks pose to critical infrastructure and intellectual property, and therefore to business operations and national security—resource constraints, both financial and human, are pervasive.

At the second dialogue, hosted by Pacific Northwest National Laboratory in Seattle in April 2018, experts across multiple sectors gathered to assess and make recommendations on the state of cybersecurity as it relates to U.S. national security. The conversation called attention to the lack of coordination across various sectors and agencies, the need to incentivize best practices in security and the importance of leveraging local and regional assets to prepare and respond to cyber-attacks.

The third and final dialogue in the series, hosted by Carnegie Mellon University in Washington, D.C., in June 2018, sought to engage federal policymakers from Capitol Hill and the administration in this important conversation and to develop an actionable agenda to improve U.S. resilience to cyber threats.

1 *The Cost of Malicious Cyber Activity to the U.S. Economy*, The Council of Economic Advisors, February 2018.

Together, the challenges, opportunities and recommendations discussed throughout the three cybersecurity dialogues—and throughout the EMCP's six sector dialogues—formed the foundation for the Council's **National Agenda for Cybersecurity** presented in this report.

The cybersecurity work was conducted under the umbrella of the Council's Energy and Manufacturing Competitiveness Partnership (EMCP), a C-suite-directed initiative focused on the shifting global energy and manufacturing landscape and how energy transformation and demand are shaping industries essential to America's prosperity and security. Critically, the EMCP approached America's diverse industrial landscape not as a monolith but as a network of distinct but interdependent productive sectors, each with its own challenges and opportunities. Throughout the exploration of six critical sectors of the U.S. economy, it became clear that cybersecurity is a significant issue that cuts across all industries and sectors, and that the United States is in need of a coordinated strategy for addressing this growing challenge.

The genesis of Council's work in this space, however, dates back to long before the launch of the EMCP in 2015. Released in 2007, ***Transform. The Resilient Economy: Integrating Competitiveness and Security*** declared, "The challenge is not security; it is resilience." The report promoted a strategy of resilience for both the public and private sectors—one that called for building America's capability to survive, adapt, evolve and grow in the face of challenges. While the challenges may have changed in the last ten years, the link between competitiveness and security is stronger than ever.

The **National Agenda for Cybersecurity** has the power to secure and strengthen America's resilience to the growing cyber threat while ensuring America remains a competitive, productive and prosperous nation.

A Call to Action

(see page 19 for full recommendations)

Secure America's Critical Assets and Infrastructure Against Cyber-attacks

1. Curtail the foreign acquisition by hostile actors of American cybersecurity assets to better manage risk. Regional powers have a growing potential to use purchased cyber tools to conduct catastrophic attacks on U.S. critical infrastructure.[2] While cyber threats from state and non-state actors come in many forms, including cyber-crime and military and political espionage, the acquisition by hostile foreign governments of U.S. cyber assets constitutes a significant security risk for the United States.

2. Leverage public and private sector purchasing power to ensure cybersecurity protections are upfront requirements throughout the value chain. While U.S. Department of Defense (DoD) contractors and subcontractors are required to meet certain security protocols, there is no universal clause across federal procurement contracts. And, industry largely lacks a consistent approach to applying best practices for security design, development and deployment of Internet-connected devices.

2 *Task Force on Cyber Deterrence*, Department of Defense Defense Science Board, February 2017.

3. Establish a means of coordinating cyber R&D investments and research agendas. When it comes to cybersecurity research, there is no community-defined research agenda, resulting in duplication of efforts and inefficient use of limited financial and human resources.

4. Develop, upgrade and deploy cybersecurity technology to enhance America's resilience to cyber-attacks. The pace of technological advancement is accelerating at record speeds, increasing vulnerability to data theft and operational disruption increases. As the threat of cyber-attacks becomes more grave, products and processes must be designed to meet basic security standards.

Strengthen America's Cyber Response and Recovery Capabilities

5. Enhance coordination across departments and agencies at the federal and state levels responsible, with the goal to improve resiliency and response to cyber threats. While numerous federal agencies are factoring cybersecurity into their programming and funding, there is minimal coordination across departments.

6. Develop agile, mobile and technically trained state and/or regional coalitions of cyber first-responders. Current recovery times from cyber-attacks are long and protracted, threatening American security and economic interests. With the average cost of a data breach in the United States at an all-time high of $7.91 million,[3] efficient incident response is critical and current assets are insufficient.

"The United States is in a digital arms race with state and private actors seeking to disrupt our economy and national security. Cybersecurity must be a national priority."

Dr. Steven Ashby
Director
Pacific Northwest National Laboratory

7. Expand access to cyber resources for small and medium-sized companies. Small businesses—those with fewer than 100 workers—represent more than 98 percent of total businesses in the United States.[4] In fact, 58 percent of data breach victims are small businesses.[5] Small businesses estimated their average cost for incidents in the last 12 months to be $34,604.[6]

8. Engage corporate leadership in the development of procedures necessary to plan for, respond to and recover from cyber incidents. Cybersecurity has become an urgent concern for companies of all sizes and across all industries. Cyber threats pose significant risks to economic security and competitiveness and have become increasingly costly in terms of detection and response.

3 *2018 Cost of a Data Breach Study: Global Overview*, Ponemon Institute, July 2018.

4 *Annual Survey of Entrepreneurs*, U.S. Census Bureau, 2016.

5 *2018 Data Breach Investigations Report*, Verizon, 2018.

6 *2018 HISCOX Small Business Cyber Risk Report*, Hiscox Inc, 2018.

Develop and Deploy a 21st Century Cyber Workforce

9. Expand and upskill the cybersecurity workforce to meet the complex and growing cyber threat. The cybersecurity field faces a constant shortage of practitioners, with approximately 350,000 current cybersecurity openings unfilled, according to CyberSeek, a project supported by the National Initiative for Cybersecurity Education (NICE).

10. Reform curricula at the nations's colleges and universities to better meet the demand for cyber-savvy students and workers. The race to respond to cyber workforce needs has led to inconsistency in program quality and stove piping of expertise. The ability of academia, industry and government to address these challenges while meeting the growing workforce demand will be a key driver of American competitiveness.

11. Break down legal and organizational barriers prohibiting or limiting cybersecurity practitioners from serving as educators. While there are significant challenges around a mismatch between supply and demand of cybersecurity professionals, academia faces a compounding challenges of a lack of educators to train the workforce of tomorrow.

Boost Cyber Awareness Among Policymakers and the Public

12. Increase the awareness and understanding of cybersecurity issues among members of Congress and their staffers. With at least 36 states D.C. and Puerto Rico having introduced and/or considered more than 265 bills or resolutions related to cybersecurity[7] and as many as 12 committees holding jurisdiction over various departments, agencies and programs addressing cyber issues, all policymakers on Capitol Hill must understand the technology and implications of cyber threats.

13. Increase the cyber awareness of the general public. An ever-evolving number of cyber threats target what is, in many ways, the weak link in the U.S. cyber ecosystem—the general public. Spam, phishing, spyware, malware, trojan horses and a litany of targeted consumer attacks can ruin personal financial security and be a gateway to a broader attack with the consumer as the entry point. Cyber savviness is no longer a luxury, but a necessity for all Americans.

7 Cybersecurity Legislation 2018, National Conference of State Legislatures, May 18, 2018.

Setting the Stage

The digitization of society, proliferation of data and increased connectedness of products and services—particularly in America's critical infrastructure sectors—have transformed the ways Americans live and organizations operate. More than 20 billion devices are expected to be connected to the Internet by 2020.[8] With this connectivity, however, comes a significant threat that can jeopardize America's critical infrastructure and, along with it, the economic viability of U.S. businesses and the freedoms Americans exercise every day: cyber-attack.

Cyber threats can come in the form of traditional cyber-crime, military and political espionage, economic espionage and cyber warfare, and carry considerable costs for the United States and the world. In fact, the White House Council of Economic Advisers estimates that malicious cyber activity—defined as an activity that seeks to compromise or impair the confidentiality, integrity or availability of computers, information or communications systems, networks, physical or virtual infrastructure controlled by computers or information systems—cost the U.S. economy between $57 billion and $109 billion in 2016[9] and is estimated to reach $2.1 trillion globally by 2019.[10] Moreover, according to the most recent data, organizations in the United States had the highest total average cost of a data breach at $7.91 million (see Figure 1).[11]

As the potential cost of cyberattacks escalates and the reliability of networks is increasingly called into question, the need to address the growing cyber threat becomes ever more urgent. Technological advancement will continue to outpace security, forcing stakeholders across all sectors of the economy—from CEOs to academics to policymakers to consumers—to move beyond the status quo and implement strong cybersecurity strategies and practices.

Asymmetric Advantage

When it comes to cyber-attacks, adversaries have an asymmetric advantage over the target: the tools needed to launch a cyber-attack are minimal, attribution is difficult if not impossible, and the impact can be devastating. The list of actors—both state and non-state—seeking to threaten U.S. economic activity is long. Members of organized criminal groups were behind half of all breaches, with nation-state or state-affiliated actors involved in 12 percent of cyber-attacks.[12] In 2017, the Pentagon made the decision to ban software made by Russian firm Kaspersky Lab, and in August 2018, President Trump signed into law a provision that would bar the federal government from purchasing equipment from Chinese telecommunications firms Huawei and ZTE Corp., a measure spurred by concerns over the potential of Chinese espionage.[13]

8 *Department of Homeland Security Cybersecurity Strategy*, May 15, 2018.

9 *The Cost of Malicious Cyber Activity to the U.S. Economy*, Council of Economic Advisers, February 2018.

10 *The Future of Cybercrime & Security*, Juniper Research, March 25, 2017.

11 *2018 Cost of a Data Breach Study: Global Overview*. Ponemon Institute LLC, July 2018.

12 2018 Data Breach Investigations Report, Verizon Enterprise Solutions, 2018.

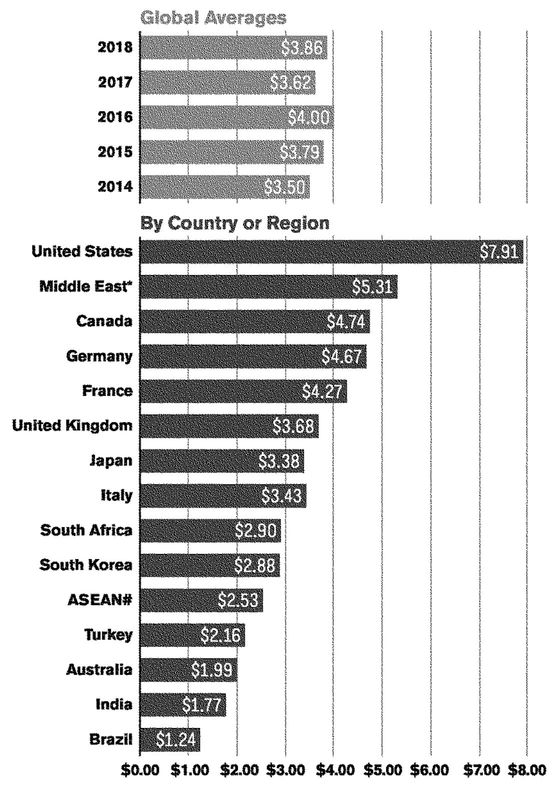
13 "Pentagon aims to shield weapons from foreign sabotage," by Ellen Nakashima, The Washington Post, August 14, 2018.

Figure 1. The Average Total Cost of a Data Breach by Country or Region
Source: *2018 Cost of a Data Breach Study: Global Overview.* Ponemon Institute LLC, July 2018.

The consolidated average per capita cost for all samples was $148, compared to an average of $141 last year.

The United States, Canada and Germany continue to have the highest per capita costs at $233, $202 and $188, respectively.

Turkey, India and Brazil have much lower per capita costs at $105, $68 and $67, respectively.



While these and other provisions are intended to shield American weapons and systems from known threats, attackers continue to hold an advantage over defenders as the first-mover that stands to incur significantly lower costs.

Critical Infrastructure

Cyber-attacks threaten American productivity and livelihoods. This is particularly true when these threats are aimed at U.S. critical infrastructure sectors, defined by the DHS as those with physical and virtual assets, systems and networks considered so vital to the United States that their incapacitation or destruction would have a debilitating effect on national and/or economic security, and national public health and/or safety.

While attacks on cyber-physical systems—smart, networked systems with embedded sensors, processors and actuators designed to sense and interact with users and support real-time, guaranteed performance in safety-critical applications—are commonly thought of as the biggest security risk to critical infrastructure, increasing reliance of business functions on IT networks has created a new frontier of vulnerabilities. And, these disruptions can be even more detrimental. As the digital and physical worlds collide, cyber-attacks have the potential to disrupt the provision of basic needs, allowing adversaries to severely harm American economic activity and daily life.

The U.S. military, in particular, has acute dependence on critical infrastructure, both domestically and internationally. The DoD has more than 15,000 computer networks among 4,000 worldwide installations, and approximately 98 percent of U.S. government communications travel over civilian owned and operated networks.[14] In fact, roughly 85 percent of U.S. critical infrastructure is privately owned or operated,[15] and these networks are highly vulnerable.

Lag in Detection Time

In the case of successful breaches, the time needed for hackers to compromise the systems under attack is most often measured in just seconds or minutes. According to Verizon's 2018 Data Breach Investigations Report (DBIR), 68 percent of breaches took months or longer to discover.[16] In 2017, it took U.S. companies an average of 201 days to detect a data breach and an average of 52 days to contain it.[17] And, it is often third parties—law enforcement, partners or customers—that discover breaches as opposed to organizations detecting breaches themselves, which was the case just 36 percent of the time in 2017.[18]

Coordination and Collaboration

Currently, multiple federal and state agencies have jurisdiction over cybersecurity in the United States. The DoD is responsible for defending the U.S. homeland and U.S. interests from attack, including attacks that may occur in cyberspace. The U.S. Department of Energy (DOE) leads the federal government's effort to ensure cybersecurity attacks do not have a catastrophic impact on the energy sector. The DHS claims responsibility for reducing vulnerabilities and

14 2013 DoD Task Force Report on Resilient Military Systems.

15 ***Critical Infrastructure Protection, Information Sharing and Cyber Security***, U.S. Chamber of Commerce, accessed October 1, 2018.

16 ***2018 Data Breach Investigations Report***, Verizon Enterprise Solutions, 2018.

17 ***2018 Cost of a Data Breach Study: Global Overview***. Ponemon Institute LLC, July 2018.

18 ***M-Trends 2018***, Mandant, A FireEye Company, 2018.

Some Helpful Definitions

Air gap: An absence of a direct or indirect connection between a computer and the Internet, affected for security reasons.

Malicious cyber activity: Activities, other than those authorized by or in accordance with U.S. law, that seek to compromise or impair the confidentiality, integrity, or availability of computers, information or communications systems, networks, physical or virtual infrastructure controlled by computers or information systems, or information resident thereon.—*NIST*

Data breach: An incident in which, without a system owner's knowledge, an actor steals sensitive, confidential or protected information through cyber activity.

Cyberspace: The online world of computer networks, and especially the Internet.—*Miriam-Webster Dictionary*

Closed-circuit, cyber-physical system: A system that integrates computation with physical processes in which the control logic is driven by measurements of the physical processes, and in turn drives the physical processes. This process reduces errors and improves stability through internal feedback.

Multi-factor authentication: A method of confirming a user's claimed identity in which a computer user is granted access only after successfully presenting two or more pieces of evidence (or factors) to an authentication mechanism, such as knowledge (something the user and only the user knows), possession (something the user and only the user has), or inherence (something the user and only the user is).

building resilience, countering malicious actors in cyberspace, responding to incidents and making the cyber ecosystem more secure and resilient. The result being that, with such a large percentage of the nation's critical infrastructure owned or operated by the private sector,[19] industry is often left to wonder where to turn in the wake of an attack.

Without a single group or entity within government designated to take charge in the face of a large-scale attack, adversaries are able to maximize their already asymmetric advantage and exploit weaknesses in U.S. response capabilities and timeliness. At the federal level, this is a legislative as well as an administrative challenge. With multiple committees of jurisdiction in Congress, coordination and communication across these committees and the departments and agencies they oversee can be a challenge and an impediment to the development and implementation of a nationwide cybersecurity plan.

With the private sector operating such a large percentage of critical infrastructure, public-private partnerships are important to the success of the United States' ecosystem as it relates to cybersecurity.

19 *Critical Infrastructure Protection, Information Sharing and Cyber Security,* U.S. Chamber of Commerce, accessed October 1, 2018.

Small and Medium-Sized Businesses

Small businesses represent more than 97 percent of total businesses in the United States. According to Verizon's 2018 DBIR, 58 percent of data breach victims are small businesses.[20] This is an indication that despite security being a growing priority for organizations of all sizes, companies that sit below the "cyber poverty line", meaning they lack the resources needed to implement perceived basic security needs and therefore have significant cyber-security risk exposure, are disproportionately targeted by attackers, creating vulnerabilities for organizations of all sizes whose operations touch these small businesses. In fact, 60 percent of smaller businesses go out of business within six months of suffering a cyber-attack.[21]

Specialized, closed-circuit cyber-physical systems have been in place in large industrial and manufacturing facilities for years. However, the economic advantages of the Internet, increasing functionality of commodity networking and information technology, and the diversification of supply chains that include many small businesses has led to new cybersecurity risks that now affect the safety and availability of the services provided by critical infrastructures.

Cyber Savviness

While the myth that cyber-attacks are often executed through air gaps—areas with indirect connections between computer and the Internet—persists, the real issue when it comes to cybersecurity is in filling knowledge gaps around information technology, research and development, and education and skills training. In fact, researchers at IBM found that 15 percent of all cyber-attacks were carried out inadvertently by insiders,[23] while as many as 24 percent of attacks may be due to employee actions or mistakes.[24]

A survey conducted by Willis Towers Watson of 92 companies from the United States found that 45 percent of 2,073 employees surveyed spent less than 30 minutes on training specific to data protection

Case Study: 140 Characters Cost U.S. Stock Market $136 Billion

In late April 2013, a tweet from the Associated Press claimed that two bombs had exploded at the White House, injuring then-President Barack Obama. The U.S. stock market reacted instantly, leading to a US$136.5 billion dip on the S&P 500 in just three minutes.

However, it was quickly discovered that the claim was false—the Twitter account had been hacked by a group calling itself the Syrian Electronic Army. When then-White House Press Secretary Jay Carney told reporters there was no explosion, the market quickly righted itself. However, not before showing the power of one tweet from a trusted source.[22]

20 2018 Data Breach Investigations Report, Verizon, 2018.

21 Champlain College, Graduate Studies, 2017; "Internet privacy in the digital age."

22 "'Bogus' AP tweet about explosion at the White House wipes billions off U.S. markets," by Peter Foster, The Telegraph, April 23, 2013.

23 2016 Cyber Security Intelligence Index, IBM X-Force Research, September 2016.

24 2016 Data Security Incident Response Report, BakerHostetler, 2016.

Transform. The Resilient Economy: Integrating Competitiveness and Security, 10 Years Later

In its 2007 report, *Transform. The Resilient Economy: Integrating Competitiveness and Security*, the Council declared, "The challenge is not security: it is resilience." This observation was made in response to the shock of 9/11, after which—for the first time in American history—it became clear that the country's economic assets and infrastructure were on the front lines of a battlefield. In 2018, while the drivers and actors may have changed in many ways, the challenges and anxieties remain the same as America finds itself standing in a new battlefield: cyberspace.

Transform identified enterprise resilience as one of three cornerstones of economic competitiveness and new value creation, along with innovation and sustainability. In the wake of 9/11, *Transform* put forth a transformational idea that there must be a business case for security and, if done right, security can lead to resilience, which has the potential to become a productivity driver and not a sunk cost.

Many of *Transform's* key findings resonate today in the context of America's cybersecurity challenges:

- Globalization, technological complexity, interdependence, terrorism, climate and energy volatility, and pandemic potential are increasing the level of risk that societies and organizations now face. Risks also are increasingly interrelated—disruptions in one area can cascade in multiple directions;
- The ability to manage emerging risks, anticipate the interactions between different types of risk, and bounce back from disruption will be a competitive differentiator for companies and countries alike in the 21st century; and
- The national objective is not just homeland protection, but economic resilience: the ability to mitigate and recover quickly from disruption.

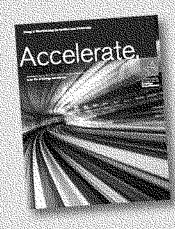
Likewise, many of the recommendations in *Transform* are mirrored in the **National Agenda for Cybersecurity**, including:

- Leverage the government's buying clout to embed resilience criteria in the procurement selection processes and supply chains; and
- Create cutting-edge, cross-disciplinary resilience curricula that prepare students for a turbulent, interdependent work environment.

Transform also warned of turbulence ahead. For the first time, new technology and infrastructure risks were listed alongside the threat of global terrorism as major threats facing the United States. It was becoming more evident that the Internet had created an entirely new set of vulnerabilities and risks that companies had not yet mastered—and still have yet to master ten years later. While 446 data breaches were reported in the United States in 2007, that number skyrocketed to 1,579 data breaches in 2017[1]—an increase of more than 350 percent.

1 Annual number of data breaches and exposed records in the United States from 2005 to 2018 (in millions), Statista, accessed October 1, 2018.

Cybersecurity: An Initiative of the Energy and Manufacturing Competitiveness Partnership



For more than two centuries, American industry has harnessed the nation's abundance of natural resources, energy, talent and ingenuity to power the most productive economy in the world. Today, the U.S. finds itself facing a new, promising frontier shaped by two powerful transformations working in tandem:

- The generational re-emergence of advanced and highly productive manufacturing capacity; and
- The increasing abundance of innovative, sustainable, affordable and domestically-sourced energy.

To capitalize on this convergence, the Council launched the Energy and Manufacturing Competitiveness Partnership (EMCP) in 2015, which leveraged more than a decade of leadership in the energy and manufacturing fields that began with the seminal National Innovation Initiative in 2003 and continued with the Energy Security, Innovation and Sustainability Initiative (2007–2009), the U.S. Manufacturing Competitiveness Initiative (2010–2011) and the American Energy and Manufacturing Competitiveness Partnership (2012–2016). The EMCP, a C-suite-directed initiative, focused on the shifting global energy and manufacturing landscape and how energy transformation and demand is shaping industries critical to America's prosperity and security.

The EMCP was designed to approach the country's diverse industrial landscape as a network of distinct but interdependent productive sectors. Through six regional sector studies hosted by members of the Steering Committee, the EMCP identified the salient questions and challenges facing the energy-manufacturing nexus. Seeking input from a cross-section of leaders, each sector study looked at the challenges and opportunities through the Council's cross-cutting competitiveness pillars—technology, talent, investment and infrastructure.

The sector studies encompassed water, advanced materials, bioscience, agriculture, energy and aerospace, allowing the EMCP to explore how the competitiveness pillars play out within each sector, identify discrete factors shaping each sector and assess common threads that span the economy. The findings and recommendations from the sector studies informed the Council's policy agenda for manufacturing excellence, presented in *Accelerate: Turbocharging the Manufacturing Renaissance in an Era of Energy Abundance*.

As part of the evolution of the EMCP, the Steering Committee identified that stakeholders across all sectors of the U.S. economy are increasingly faced with the threat of cyber-attacks that put information, infrastructure and overall security at risk. In 2018, the Council launched a three-dialogue series on the challenges and opportunities related to cybersecurity.

The **National Agenda for American Cybersecurity**, presented in this report, is informed by those three dialogues and builds on the work of the EMCP.

and information security in the last 12 months.[25] Of that 45 percent, more than half had received no training at all. Those surveyed cite insufficient employee understanding of cyber risks, ineffective structures and processes, and insufficient budgets as the top three barriers preventing their organizations from effectively managing cyber risks.[26]

Workforce Challenges

It is vitally important that the United States has an adequate, viable cybersecurity workforce to secure critical infrastructure, but also to address a myriad of national security and domestic concerns. In 2017, the National Initiative for Cybersecurity Education (NICE) reported that 285,000 cybersecurity roles went unfilled in the United States alone.[27] The (ISC)² Global Information Security Workforce Study (GISWS) estimates that over a quarter-million positions went unfilled in the United States in 2016 and a predicted shortfall of 1.5 million cybersecurity professionals by 2020.[28] Other estimates project the demand for cybersecurity professionals will exceed the supply by as many as 3.5 million by 2021.[29]

The race to respond to cyber workforce needs has led to inconsistency in program quality and stove piping of expertise. The ability of academia, industry and government to address these challenges, while meeting current and future needs, will be a key driver of American competitiveness in this burgeoning field.

25 ***Decoding Cyber Risk: 2017 Willis Towers Watson Cyber Risk Survey (US results)***, Willis Towers Watson, 2017.

26 Decoding Cyber Risk: 2017 Willis Towers Watson Cyber Risk Survey (US results), Willis Towers Watson, 2017.

27 ***M-Trends 2018***, Mandant, A FireEye Company, 2018.

28 ***(ISC)² Global Information Security Workforce Study (GISWS)***, Frost & Sullivan, April 17, 2015.

29 Cybersecurity Jobs Report, Cybersecurity Ventures, May 2017.

Case Study: Spear-Phishing Attack Infiltrates U.S. Universities

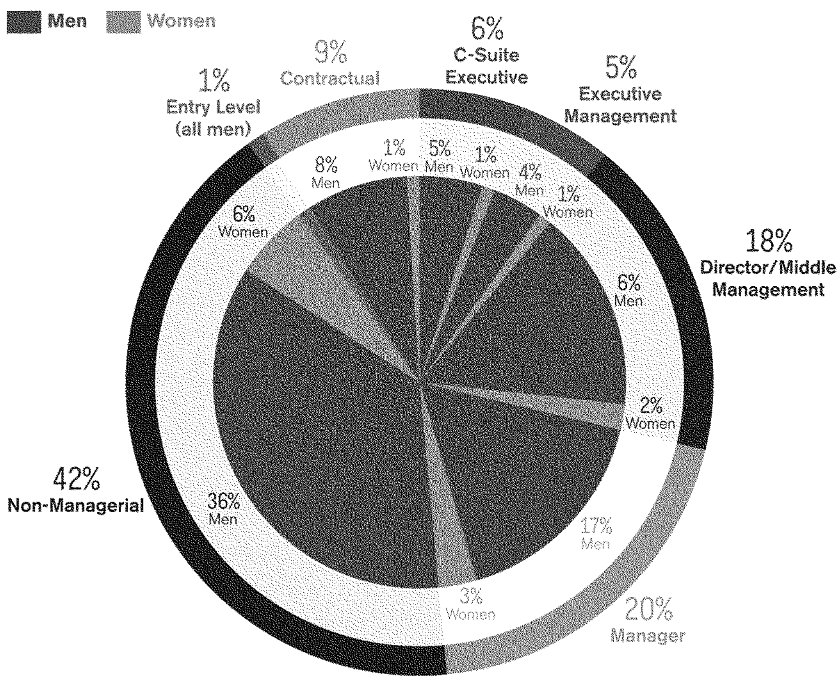
In 2018, nine Iranian hackers were indicted by the Department of Justice for hacking 144 U.S. universities, 47 private organizations and a handful of U.S. government agencies. The three-year campaign resulted in the loss of $3 billion in intellectual property. The hackers utilized spear-phishing emails to target professors by getting them to click on malicious links and entering login credentials. The hackers managed to successfully penetrate nearly 4,000 accounts at U.S. schools.

Nearly two years earlier, charges were brought by the U.S. Department of Justice against seven Iranians for conducting distributed denial-of-service attacks targeting Wall Street and the financial sector as well as for penetrating a dam control system. These attacks are evidence of the ability of political tension to spill into the digital world, creating a new, 21st century battlefield.

Moreover, women currently comprise just 14 percent of the information security workforce in North America—34 percentage points lower than the average of women in the workforce (see Figure 2).[30]

30 The 2017 Global Information Security Workforce Study: Women in Cybersecurity, Frost & Sullivan, 2017.

Figure 2. Gender Distribution by Organizational Position of the Cybersecurity Workforce
Source: 2017 Global Information Security Workforce Study, (Women n= 2,134; Men n=16,679)
Note: Some percentages may not add up to 100 percent due to rounding.



And, while minority representation within the cybersecurity profession (26 percent) is slightly higher than the overall U.S. minority workforce (21 percent), just 23 percent of minority cybersecurity workers hold a role of director or above, 7 percent below the U.S. average.[31] Consequently, policies that encourage greater participation in the cybersecurity workforce will be essential if the United States hopes to meet the growing demand for cyber professionals.

Conclusion

Rapid advancement in cyber technology development is being fueled by industry modernization, e-commerce and consumer entertainment. The interconnectedness and openness made possible by the Internet and broader digital ecosystem create unparalleled value for society.

But these same qualities make securing today's cyber landscape difficult. Technological advancement is outpacing security and will continue to do so unless the United States changes the way it approaches and implements cybersecurity strategies and practices. Cybersecurity requires a comprehensive, national agenda to secure, enhance and strengthen America's resilience to cyber-attacks and ensure the nation is equipped with the tools and talent needed to remain a global leader in technology and innovation.

"Cyber-attacks are a constant threat to the increasingly interconnected digital backbone of the U.S. economy and will require coordination among industry, academia and government to mitigate the risk."

Mr. George Fischer
Senior Vice President and Group President
Verizon Enterprise Solutions

31 Labor force characteristics by race and ethnicity, U.S. Bureau of Labor Statistics, 2015.

A National Agenda for Cybersecurity

A national cyber agenda must ensure the United States has the infrastructure, technology and talent needed to build resilience to cyber-attacks, along with the ability to respond and recover in the event of such attacks.

The interconnectedness and openness made possible by the Internet and the broader digital ecosystem create unparalleled value for society. The architects of the Internet could not know, however, that it would reach the breadth and scope seen today. Throughout human history, technological advancement has outpaced security. While this is unlikely to change, America's ability to remain resilient in the face of increasing cyber threats will require a shift in the understanding of—and dynamic between—innovation and security. The evolution to a new way of thinking that focuses on deliberate, risk-informed trade-offs will be essential.

What follows are a series of concrete, actionable recommendations cutting across the public and private sectors that, taken together, will strengthen U.S. cyber defenses and ensure greater resilience in the face of growing and malicious cyber threats.

Secure America's Critical Assets and Infrastructure Against Cyber-attacks

With the average cost of a data breach in the United States at an all-time high of $7.91 million and over 1,300 significant breaches in the last year, malicious cyber activity in the United States is a substantial threat to America's economic and national security.[32] The increasing sophistication of cyber-attacks poses a constant threat to critical infrastructure. And as the availability of networks is called into question every day, the economic viability of U.S. businesses and the freedoms Americans exercise daily are in jeopardy.

1. Curtail the foreign acquisition by hostile actors of American cybersecurity assets to better manage risk. Regional powers have a growing potential to use purchased cyber tools to conduct catastrophic attacks on U.S. critical infrastructure.[33] While cyber threats from state and non-state actors come in many forms, including cyber-crime and military and political espionage, the acquisition by hostile foreign governments of U.S. cyber assets constitutes a significant security risk for the United States.

Recommendations

1.1. Require under the new authorities of the Foreign Investment Risk Review Modernization Act (FIRRMA) in the National Defense Authorization Act for Fiscal Year 2019 that the Committee on Foreign Investment in the United States (CFIUS) conduct full reviews and regulatory approval for any foreign investment or ownership interest in American advanced cybersecurity startups, joint ventures or acquisitions.

32 *2018 Cost of a Data Breach Study*, Ponemon Institute, July 2018.

33 *Task Force on Cyber Deterrence*, Department of Defense Defense Science Board, February 2017.

1.2. Require all U.S. securities and SEC-registered securities and investment funds of any size to provide the U.S. Department of the Treasury and the FBI full transparency on sources of investment capital and intellectual property, and limit partners from countries deemed high-risk or sanctioned by the Treasury Department.

1.3. Expand the authority of the Bayh-Dole Act and federal tech transfer act to prevent the licensing of U.S. cyber technology developed with federal funding to foreign countries deemed high risk.

2. Leverage public and private sector purchasing power to ensure cybersecurity protections are upfront requirements throughout the value chain. While DoD contractors and subcontractors are required to meet certain security protocols, there is no universal clause across federal procurement contracts. And, industry largely lacks a consistent approach to applying best practices for security design, development and deployment of Internet-connected devices.

Recommendations

2.1. Extend Defense Federal Acquisition Regulation Supplement DFAR 252.204-7012 language mandating adequate security to all government agencies.

2.2. Call on Congress to take immediate action on the Internet of Things ('IoT') Cybersecurity Improvement Act of 2017, requiring the inclusion of specific cybersecurity protections in procurement contracts with all federal and state agencies for Internet-connected devices.

2.3. Incentivize vendors' awareness and adoption of security best practices utilizing industry purchasing power.

2.4. Promote greater uptake and use of existing cybersecurity standards to increase supply chain security.

3. Establish a means of coordinating cyber R&D investments and research agendas. When it comes to cybersecurity research, there is no community-defined research agenda, resulting in duplication of efforts and inefficient use of limited financial and human resources.

Recommendations

3.1. Establish the National Cybersecurity R&D Initiative, chaired by the White House Science Advisor, to identify challenges, solicit industry input, define priorities and, on an ongoing basis, coordinate government investment to optimize talent and resources and avoid duplication of efforts.

3.2. Convene a Basic Research Needs working group including leaders from the public and private sectors to define a set of research priorities to address the technology R&D challenges and Science Grand Challenges that, if solved, will strengthen U.S. cybersecurity capability.

3.3. Create data-driven processes to develop specific cybersecurity countermeasures unique to sectors and sub-sectors, and disseminate these processes through Information Sharing and Analysis Centers and Community Emergency Response Teams to mitigate the risk of cyber incidents.

4. Develop, upgrade and deploy cybersecurity technology to enhance America's resilience to cyber-attacks. The pace of technological advancement is accelerating at record speeds, increasing vulnerability to data theft and operational disruption increases. As the threat of cyber-attacks becomes more grave, products and processes must be designed to meet basic security standards.

Recommendations

4.1. Require that all new technology applied to the electric grid meet industry standards to ensure basic cybersecurity.

4.2. Expand funding and private sector engagement for testbeds for the creation and adoption of new cybersecurity technologies such as Digital Manufacturing Design and Innovation Institute (DMDII) Cyber Hub for Manufacturing and the Army Cyber-research Analytics Laboratory.

4.3. Expand the NIST cybersecurity framework to better guide secure development of IoT, operational technology (OT) and information technology (IT) platforms and technologies as a means to bolster private industry certification programs.

Strengthen America's Cyber Response and Recovery Capabilities

According to the latest data, in the United States, the average time required to identify a data breach incident is 201 days, while the average amount of time to contain a breach is 52 days.[34] America's ability to detect, withstand and recover from cyber events that disrupt the economy and society in a quick and coordinated manner is essential for the nation's security and competitiveness.[35]

5. Enhance coordination across departments and agencies at the federal and state levels responsible, with the goal to improve resiliency and response to cyber threats. While numerous federal agencies are factoring cybersecurity into their programming and funding, there is minimal coordination across departments.

Recommendations

5.1. The administration should reinstate and empower a White House cybersecurity czar to oversee a government-wide interagency task force to develop and implement, within 180 days, a coordinated cyber defense strategy that includes mechanisms for owners and operators of critical infrastructure to more easily share appropriate data.

5.2. Governors should convene state and local representatives from across the public and private sectors to develop statewide cyber-attack prevention and response strategies.

34 "IBM Study: Hidden Costs of Data Breaches Increase Expenses for Businesses," PRNewswire, IBM Security, July 11, 2018.

35 "Protecting Small Businesses from Cyber Attacks: the Cybersecurity Insurance Option", Testimony of Robert Luft, Owner, Surefire Innovations, National Small Business Association, July 26, 2017.

5.3. Convene biannual meetings of the private sector chairpersons of federal government advisory committees and external boards to share agency priorities, best practices and identify areas to strengthen interagency collaboration.

6. Develop agile, mobile and technically trained state and/or regional coalitions of cyber first-responders. Current recovery times from cyber-attacks are long and protracted, threatening American security and economic interests. With the average cost of a data breach in the United States at an all-time high of $7.91 million,[36] efficient incident response is critical and current assets are insufficient.

Recommendations

6.1. Institute state Cyber Protection Teams through the National Guard Bureaus and tactical analysis groups.

6.2. Governors and state legislators must provide funding and reduce legal and liability barriers to resources acting in state capacity.

6.3. Expand to additional states existing programs[37] to provide veterans with access to cybersecurity training opportunities and resources to help veterans enter the cybersecurity workforce.

6.4. Establish and fund, at the state level, "civilian reserve cyber corps" comprising volunteers from private industry security and IT professionals to be deployed in the event of a regional cyber incident.

6.5. Create a tiered technology approach to cyber that enables technically-trained cyber experts—people who are experts in using tools but that don't require advanced degrees—to obtain the technical skills needed to act in this capacity.

7. Expand access to cyber resources for small and medium-sized companies. Small businesses—those with fewer than 100 workers—represent more than 98 percent of total businesses in the United States.[38] In fact, 58 percent of data breach victims are small businesses.[39] Small businesses estimated their average cost for incidents in the last 12 months to be $34,604.[40]

Recommendations

7.1. Sustain funding for the Manufacturing Extension Partnership (MEP) National Network and expand resources available for cybersecurity tools and training and certification such as the NIST MEP Cybersecurity Assessment Tool.

7.2. State and metropolitan Small Business Administrations should establish cybersecurity training initiatives in partnership with Workforce Development Boards to reach a broad array of small and medium-sized businesses below the cyber poverty line.

7.3 Expand federal and state outreach to small and medium-sized businesses to increase knowledge of existing resources, including top resources identified by the DHS U.S. Computer Emergency Readiness Team (US-CERT).

36 ***2018 Cost of a Data Breach Study: Global Overview***, Ponemon Institute, July 2018.

37 Cyber Virginia: Cyber Veterans Initiative, The Commonwealth of Virginia, July 2017.

38 ***Annual Survey of Entrepreneurs***, U.S. Census Bureau, 2016.

39 ***2018 Data Breach Investigations Report***, Verizon, 2018.

40 ***2018 HISCOX Small Business Cyber Risk Report***, Hiscox Inc, 2018.

8. Engage corporate leadership in the development of procedures necessary to plan for, respond to and recover from cyber incidents. Cybersecurity has become an urgent concern for companies of all sizes and across all industries. Cyber threats pose significant risks to economic security and competitiveness and have become increasingly costly in terms of detection and response.

Recommendations

8.1. Corporate cybersecurity leads should report directly to executive team members and align responsibilities with risk management strategies.

8.2. Companies should embrace the Securities and Exchange Commission Guidance on Public Company Cybersecurity Disclosures[41] and take all required actions to inform investors of material cyber risks and incidents in a timely fashion.

Develop and Deploy a 21st Century Cyber Workforce

Further adding to the growing risk of cyber threats to American prosperity, the world is on pace to reach a cybersecurity workforce gap of 1.8 million by 2022.[42] It is vitally important that the United States have an adequate cybersecurity workforce to secure the nation's critical infrastructure; respond to the ever-expanding cyber threat; and equip businesses of all sizes and governments at all levels with the talent to meet the next generation of cyber challenges.

9. Expand and upskill the cybersecurity workforce to meet the complex and growing cyber threat. The cybersecurity field faces a constant shortage of practitioners, with approximately 350,000 current cybersecurity openings unfilled, according to CyberSeek, a project supported by the National Initiative for Cybersecurity Education (NICE).

Recommendations

9.1. Ensure NSF funding for the CyberCorps®: Scholarship for Service (SFS) program meets the growing demand.

9.2. The National Science Foundation should expand and expedite the implementation of the Community College Cyber Pilot Program (C3P) under the CyberCorps® SFS program.

9.3. Congress should take immediate action to pass S. 754, Cyber Scholarship Opportunities Act of 2017 to permanently extend support for cybersecurity education in primary and secondary schools.

9.4 Expand cybersecurity awareness programs in secondary schools to increase interest and awareness of students from diverse backgrounds regarding career opportunities in the cybersecurity field.

41 Commission Statement and Guidance on Public Company Cybersecurity Disclosures, 2018.

42 *2017 Global Information Security Workforce Study*, Frost & Sullivan, 2017.

10. Reform curricula at the nations's colleges and universities to better meet the demand for cyber-savvy students and workers. The race to respond to cyber workforce needs has led to inconsistency in program quality and stove piping of expertise. The ability of academia, industry and government to address these challenges while meeting the growing workforce demand will be a key driver of American competitiveness.

Recommendations

10.1. Expand the number of colleges and universities with programs and credentials that meet the criteria required for designation as National Centers of Academic Excellence in Cyber Operations or Cyber Defense by the National Security Agency and the DHS.

10.2. Embed cybersecurity concepts into a broad range of existing degree programs at the university level.

11. Break down legal and organizational barriers prohibiting or limiting cybersecurity practitioners from serving as educators. While there are significant challenges around a mismatch between supply and demand of cybersecurity professionals, academia faces a compounding challenges of a lack of educators to train the workforce of tomorrow.

Recommendations

11.1. States and educational institutions must reduce barriers to allow cybersecurity practitioners to serve as professors of practice.

11.2. Establish industry-academia-national laboratory exchange programs to facilitate cross-pollination between cyber experts and practitioners.

Boost Cyber Awareness Among Policymakers and the Public

Human error is one of the most significant challenges when it comes to protecting against cyber-attacks. In fact, 90 percent of cyber incidents are human-enabled,[43] while as many as 24 percent of attacks may be due to employee actions or mistakes. [44]

12. Increase the awareness and understanding of cybersecurity issues among members of Congress and their staffers. With at least 36 states, D.C. and Puerto Rico having introduced and/or considered more than 265 bills or resolutions related to cybersecurity[45] and as many as 12 committees holding jurisdiction over various departments, agencies and programs addressing cyber issues, all policymakers on Capitol Hill must understand the technology and implications of cyber threats.

Recommendation

12.1. Members in the House of Representatives and Senate should reinvigorate the bipartisan House and Senate Cyber Caucuses, which have been largely dormant in recent years, to provide members of Congress and their staffers with access to experts in the field.

43 Shifting the Human Factors Paradigm in Cybersecurity, Calvin Nobles, Ph.D., March 15, 2018.

44 2016 Data Security Incident Response Report, BakerHostetler, 2016.

45 Cybersecurity Legislation 2018, National Conference of State Legislatures, May 18, 2018.

13. Increase the cyber awareness of the general public. An ever-evolving number of cyber threats target what is, in many ways, the weak link in the U.S. cyber ecosystem—the general public. Spam, phishing, spyware, malware, trojan horses and a litany of targeted consumer attacks can ruin personal financial security and be a gateway to a broader attack with the consumer as the entry point. Cyber savviness is no longer a luxury, but a necessity for all Americans.

Recommendations

13.1. Fund, develop and implement a major national cyber-awareness campaign, that builds on existing efforts, to increase the general public's awareness and capability to prepare for and respond to cyber threats.

13.2. Call on local economic development authorities to put in place programs that encourage cybersecurity education at the K-12 level.

13.3. Implement and enforce basic cybersecurity protocols throughout industry, government and academia including patching, multi-factor authentication and identity management as standard business practices.

"With the proliferation of interconnected devices, industries and organizations, the need for cyber expertise is quickly outpacing supply, creating an urgent need for colleges and universities to innovate curricula and program offerings in this field."

Dr. Farnam Jahanian
President
Carnegie Mellon University:

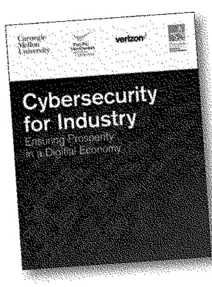
Cybersecurity Dialogue Series

DIALOGUE 1

Cybersecurity for Industry: Ensuring Prosperity in a Digital Economy

February 2, 2018
Basking Ridge, NJ

Hosted by: Mr. George Fischer
Senior Vice President & Group President
Verizon Enterprise Solutions



Rapid advancement in cyber technology development is being fueled by industry modernization, e-commerce and consumer entertainment. The interconnectedness and openness made possible by the Internet and the broader digital ecosystem creates unparalleled value for society. Advancements in computing, networking and communications technology permeate through every sector of the economy and are being made at a pace that is both breathtaking and unprecedented in human history. But these same qualities make securing today's cyber landscape extremely challenging. Technological advancement is outpacing security and will continue to do so unless the United States changes the way it approaches and implements cybersecurity strategies and practices.

With attribution of cyber-attacks becoming more difficult, and with these events happening at increasing rates, companies and organizations need a revised tool set to handle cyber-attacks quickly and effectively. And as adversarial AI becomes significantly more sophisticated in the next three to five years, the need to promote a cyber moon shot becomes increasingly more urgent. Cybersecurity is no longer a predominantly tech-related problem—due to the tremendous financial burden of cyber-attacks incurred as a consequence of disruption to operations, loss of data and cost of security, among other concerns, cyber-attacks have become a risk management issue, while strong cyber defense/response can be a productivity enabler.

Despite the clear importance of cybersecurity in the current technological and political climate—and the threat cyber-attacks pose to critical infrastructure and intellectual property, and therefore to business operations and national security—resource constraints, both financial and human, are pervasive. Small and medium-sized companies often face budgetary constraints that preclude them from affording the latest security technology. And firms of all sizes see talent shortages and knowledge gaps that leave them vulnerable to cyber risks and slow to recover from cyber-attacks.

These are just a few of the multidimensional security challenges companies in the United States face in an era marked by transformational innovation and the digitization of an exponential amount of data. These challenges, while difficult and numerous, are not insurmountable. They will, however, require collaboration on the parts of both the public and private sectors to improve America's mitigation, adaptability and resilience to the growing number of cyber threats from state and non-state actors.

Initial Findings

Voluntary, industry-led cybersecurity standards, created in partnership with the government, are needed. While risk management frameworks and industry guidelines around cybersecurity exist, there is a need for industry-sponsored standards that define basic cybersecurity terms, and set security thresholds for products and systems. These standards could be used to benchmark security posture and create a competitive advantage for companies. The National Institute of Standards and Technology (NIST) could act as an umbrella infrastructure for these standards.

Security must be integrated into products and processes early on in the development cycle, rather than being considered an add-on component. As the pace of technological advancement accelerates at record speeds and products become increasingly connected through the proliferation of sensors and data, vulnerability to data theft and operational disruption increases. As the threat of cyber-attacks becomes more grave, products and processes must be designed with cyber resiliency in mind.

An overwhelming amount of data creates challenges with regard to credibility of cyber threats and ability to operationalize data. With the volume of useful, actionable information greater than ever before, a balance must be struck between information sharing required for legitimate policy interests and guarding private enterprise interests. Standardizing the gathering and valuation of cybersecurity data would improve security across all industries, but building trusted relationships is currently the best way to facilitate sharing of high-quality data on cybersecurity threats and attacks.

Cybersecurity must be transformed into a competitive advantage rather than a sunk cost by focusing on the confluence of risk, capabilities and resources. By treating cybersecurity as a precompetitive issue, being proactive in addressing threats rather than reactive to attacks, and looking at cyber technologies and cybersecurity posture as valued capital rather than as a liability, companies can raise their security posture and insulate themselves from cyber threats. This requires more research into quantifiable risk that can enable a meaningful regulatory approach and insurance market that should in time be rewarded by the market.

All organizational levels, including company boards and C-suite leaders, must be engaged in cyber planning, response and recovery efforts. Cybersecurity is often considered the job of policy and IT experts. A shift in organizational culture across all organizational functions and levels to view cybersecurity as an issue of larger corporate relevance, rather than simply a technology problem, is necessary to improve companies' ability to protect against, respond to and recover from cyber-attacks.

Industry and academia must work together to create a baseline curricula to educate a knowledgeable, cyber-savvy workforce. It is vitally important for the United States to have an adequate, viable cybersecurity workforce with a consistent, baseline level of knowledge. Diversity and inclusion will be essential in order to meet the burgeoning needs in this field. Hands-on experience and mentorship programs would also help increase interest while combatting the slow pace of curriculum change. It would also be mutually beneficial for industry and academia to cross-pollinate and cycle practitioners and educators through both worlds.

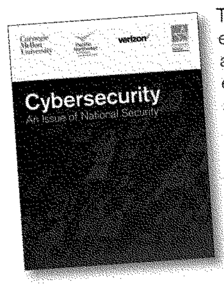
Cybersecurity must be integrated into educational curricula outside traditional four-year universities and post-grad studies, including high schools and community colleges. The responsibility of educating on cybersecurity and computer science should not rest entirely on college and universities. College-level courses in cyber or computer science at the high school level would help expand the talent pool. Community colleges, with the support of industry executives, should also be considered a viable option for students and a viable recruitment pool for employers.

DIALOGUE 2

Cybersecurity: An Issue of National Security

April 25, 2018
Seattle, WA

Hosted by: Dr. Steven Ashby
Director
Pacific Northwest National Laboratory



The digitization of society, proliferation of data and increased connectedness of products and services—particularly in America's critical infrastructure sectors—have transformed the ways Americans live and organizations operate. Yet, the tremendous growth in the level of connectivity poses risks to U.S. global competitiveness as firewalls become the next frontline for battle in the United States. As a result, cybersecurity has become an issue of national security.

The United States is facing a steady increase in the volume, types and sophistication of cyber-attacks. Organizations of all types—including industry, government, academia and national laboratories—are assailed relentlessly by efforts from state and private entities to disrupt operations, steal information and increase their own competitiveness. These threats, which come in the form of traditional cyber-crime, military and political espionage, economic espionage and cyber warfare, carry considerable costs for the United States and the world. In fact, a study by Juniper Research suggests the annual cost of data breaches will reach $2.1 trillion globally by 2019, an increase of almost four times the estimated cost of breaches in 2015.[46]

Cyber-attacks are particularly concerning when it comes to the 16 critical infrastructure sectors as defined by the DHS[47]—each of which plays an integral role in America's economic and national security. A reliable energy grid, for example, is essential for any institution to operate. And while the DOE currently has plans to improve preparedness, response and recovery capabilities, 90 percent of the energy grid is operated by private companies—requiring strong public and private partnerships to ensure

46 The Future of Cybercrime & Security, Juniper Research, March 25, 2017.

47 PPD-21 identifies 16 critical infrastructure sectors: chemicals; commercial facilities; critical manufacturing; dams; defense industrial base; emergency services; energy; financial services; food and agriculture; government facilities; healthcare and public health; information technology; nuclear reactors; materials and waste; sector-specific agencies; transportation systems; and water and wastewater systems. https://www.dhs.gov/critical-infrastructure-sectors.

these suppliers are resilient against and have the tools needed to respond quickly to potential cyber-attacks.[48]

The increasing sophistication of cyber-attacks poses a constant threat to critical infrastructure. And as the availability of networks is called into question every day, the economic viability of U.S. businesses and the freedoms Americans exercise daily are in jeopardy.

Initial Findings

Cybersecurity should be built into industry and government contracts to incentivize broader adoption. Cybersecurity must be better incentivized using new, innovative market mechanisms. This could include building security into procurement mechanisms or advancing how technologies are measured for security in order to institutionalize the adoption of security measures across the supply chain.

A unified, clear research agenda across industry and government is needed in the cybersecurity space. When it comes to cybersecurity research, there is no clear, community-defined research agenda, resulting in duplication of efforts and inefficient use of limited financial resources. A mechanism is needed to organize the research community and marshal appropriate stakeholders and topics to shape the research agenda.

Effort is needed to connect industry with laboratory and academic research to ensure knowledge transfer and reduce duplication. Discoverability of existing capabilities—both on the part of industry and the R&D community—is a significant challenge. Better coordination would reduce duplication of efforts—both within and across these communities—and help better align research priorities and commercial needs to scale-up security solutions.

There must be a clearly-articulated federal model for cyber response to critical infrastructure attacks. While numerous government agencies are factoring cybersecurity into their programming and funding, there is minimal coordination across these programs. This would decrease duplication of efforts and improve resiliency and response capabilities in the face of cyber threats.

There is an opportunity at the state or regional level to capitalize on the patriotism, altruism and tech savviness of younger generations to create coalition(s) of cyber first-responders. Current recovery times from cyber-attacks are long and static, threatening American security and economic interests. The United States needs a coordinated first-response effort to further regional cyber protection and response. One potential home for this effort could be within the National Guard.

Globally-defined, security baselines are needed and must be informed by relevant stakeholders. Useful and practical security baselines would level the playing field and set basic expectations around how systems and networks can be deployed in recommended, secure configurations. Advances must be made through the product lifecycle to improve design, default and deployment, thereby building assurance around the resiliency of critical infrastructure to cyber-attacks and disruption.

48 https://www.energy.gov/oe/activities/cybersecurity-critical-energyinfrastructure.

Applying automated security monitoring to critical infrastructure sectors would significantly improve cyber defense. When applied to the observe-orient-decide-act loop, continual evaluation of security through artificial intelligence and machine learning can enable adversary detection, attribution and action prediction and improve response in a way that would reduce the asymmetric advantage of attackers and level the cyber defense playing field for critical infrastructure providers.

Cybersecurity must be integrated into the academic curricula of related topics. While training cybersecurity professionals is a valuable endeavor, cybersecurity must be a key educational component for computer scientists, engineers and other professions in which security is a foundational concern. This will increase the pool of professionals with relevant and applicable cybersecurity skills across the most critical areas of need and ensure that future engineers across all disciplines are able to design and build secure systems.

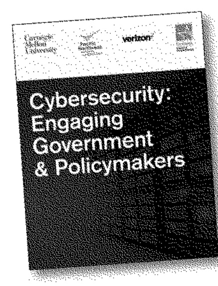
Barriers prohibiting practitioners to serve as educators must be reduced. While there are significant challenges around a mismatch between supply and demand of cybersecurity professionals, academia faces the compounding challenge of a lack of educators to train the workforce of tomorrow. A strategic effort on the part of industry and academia is needed to fill this gap.

DIALOGUE 3

Cybersecurity: Engaging Government & Policymakers

June 19, 2018
Washington, D.C.

Hosted by: Dr. Farnam Jahanian
President
Carnegie Mellon University



As computing power rapidly increases, the United States faces the challenge of protecting the latest technology from the increasing threat of cyber-attacks. This task will only become more difficult given the rising number of devices connected to the electric grid as smart homes and buildings become the norm. Although the United States is progressively making cybersecurity a higher priority for the nation, there is still much work to be done to secure critical infrastructure.

With the United States already at a disadvantage in comparison to its adversaries, U.S. policymakers must act to build resilience to the increasing threat and occurrence of cyber-attacks. Without a single group or entity within government designated to take charge in the face of a large-scale attack, adversaries are able to maximize their already asymmetric advantage and exploit weaknesses in U.S. response capabilities. And while agencies like the DOE have taken critical steps to protect America's energy infrastructure, coordination and effective communication with Congress is necessary to ensure efficient use of the limited resources available to support nationwide cybersecurity.

Simultaneously, the challenges posed by the increasing cyber threat from state and non-state actors continue to outpace the size of the workforce equipped with the skills to mitigate the growing risk. While programs exist throughout the federal government—including the National Science Foundation's CyberCorps®: Scholarship for Service, a scholarship program to recruit and train the next generation of information technology professionals, industry control system security professionals and security managers—these efforts must be amplified in order to keep pace with the growing need for cybersecurity professionals.

Together, policymakers across all federal agencies must address the growing threat of cyberattack to the United States. Coordination and collaboration are essential if the United States is to secure itself against the threat of attack, enhance cyber resilience, strengthen the cyber workforce and boost the awareness needed to remain competitive.

Initial Findings

There must be a clear, practical model for cyber response that identifies roles and responsibilities of the public and private sectors. Numerous federal agencies currently have jurisdiction over different aspects of cybersecurity, leaving uncertainty as to where responsibilities lie in the wake of an attack. Similarly, there is a lack of clarity on the part of industry as to the requirements. Clear leadership in the cybersecurity space would help the United States maintain its competitive advantage by thwarting cyber threats.

Small and medium-sized businesses often lack access to the knowledge and resources needed to maintain an appropriate level of cybersecurity. Much of industry is below the cyber "poverty line," meaning they do not have access to the resources needed for basic cyber hygiene, much less defense against nation-states. These businesses can serve as a gateway into larger organizations for attackers. Tools and guidance for small and medium-sized businesses would improve supply chain cybersecurity overall.

Tools for assessing the performance, benefit and risk associated with cyber tools must be developed. Independent consumer reports, tests or assurance programs that correlate to improved cybersecurity posture would improve supply chain security and enable the uptake of proven security technologies.

The current talent pool cannot meet the rising demand for cybersecurity workers. Without intervention, the United States will experience a debilitating lack of talent to fill cybersecurity needs essential for maintaining competitive advantage globally. Tools must be developed to train cybersecurity professionals at all levels—from first response practitioners to experts.

Cybersecurity must be incentivized as a risk management issue to raise the overall security posture of American industry and critical infrastructure. When cybersecurity is perceived by businesses as a cost, decisions are made from a cost-benefit perspective rather than a risk management vantage point. This becomes a challenge as cybersecurity risks span beyond the source of the incident. Cyber protections and processes must be valued as capital rather than cost.

Security must be built into products and systems from the very earliest stages of development. The pace of innovation and technology uptake by the general public has historically been driven by convenience and functionality, as opposed to security. This creates a situation where technology is used long before its security implications are understood. Creating a basic blueprint that provides a succinct path for security-enabled technologies to transition from research to market will minimize stranded research and increase the overall security posture of the United States by facilitating the introduction of new, more secure products to the market.

About the Council on Competitiveness

For more than three decades, the Council on Competitiveness (Council) has championed a competitiveness agenda for the United States to attract investment and talent, and spur the commercialization of new ideas.

While the players may have changed since its founding in 1986, the mission remains as vital as ever—to enhance U.S. productivity and raise the standard of living for all Americans.

The members of the Council—CEOs, university presidents, labor leaders and national lab directors—represent a powerful, nonpartisan voice that sets aside politics and seeks results. By providing real-world perspective to Washington policymakers, the Council's private sector network makes an impact on decision-making across a broad spectrum of issues from the cutting-edge of science and technology, to the democratization of innovation, to the shift from energy weakness to strength that supports the growing renaissance in U.S. manufacturing.

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

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APPENDIX A

Compete.
Council on Competitiveness

Ensuring Prosperity and National Security in a Digital Economy
An initiative of the Energy and Manufacturing Competitiveness Partnership

Background

America's critical infrastructure is an integral part of national security and homeland security. Maintaining the 16 critical infrastructure sectors, which include critical manufacturing, energy, financial services and transportation, requires coordinated action on the part of government (federal, state, and local), the private sector, and the U.S. military.

The U.S. military has acute dependence on critical infrastructure both domestically and internationally. The Department of Defense has over 15,000 computer networks among 4,000 worldwide installations, and approximately ninety-eight percent of U.S. government communications travel over civilian owned and operated networks.[1] In fact, roughly eighty-five percent of U.S. critical infrastructure is privately owned or operated, and these networks are highly vulnerable. The significant cybersecurity threat jeopardizes America's critical infrastructure and, along with it, the economic viability of U.S. businesses and the freedoms Americans exercise every day.

Despite the notable risk cyber threats pose to American prosperity, there is a wide disparity in investment, maturity, coordination and training on cybersecurity across the various critical infrastructure sectors. According to the US Bureau of Labor Statistics, in 2016 the cybersecurity field experienced an increasing shortage of practitioners with over a quarter-million positions remaining unfilled in the US alone and a predicted shortfall of 1.5 million cybersecurity professionals by 2019. Yet cyberspace is the nervous system of critical infrastructure sectors– both in terms of traditional information technology and operational technology.

According to the Department of Homeland Security, 56 percent of all cyber incidents against critical infrastructure in 2013 were directed at energy infrastructure, mostly the electric grid. In the 2017 Verizon Data Breach Investigations Report, it reported that 63% of breaches of manufacturing and utilities were cyber-espionage related with the majority of those attacks were triggered by phishing. Almost ¾ of breaches were attributed to state-affiliated threat actors.[2] This figure has declined as cyber-attacks against other critical infrastructure have grown, but the threat to our energy infrastructure remains high. Failure to take responsible action leaves the U.S.

[1] 2013 DoD Task Force Report on Resilient Military Systems
[2] 2017 Verizon Data Breach Investigations Report

vulnerable to a variety of threats. Nation-states such as Russia, China, and Iran threaten U.S. critical infrastructure and assets in the interest of furthering their objectives. Cyber espionage is rampant, with U.S. companies estimated to be losing a staggering $300 billion every year in intellectual property.

Rapid advancement in cyber technology development is being fueled by industry modernization, e-commerce and consumer entertainment. The interconnectedness and openness made possible by the Internet and broader digital ecosystem create unparalleled value for society. But these same qualities make securing today's cyber landscape difficult. Technological advancement is outpacing security and will continue to do so unless we change the way we approach and implement cybersecurity strategies and practices.

Objectives

The Council, in partnership with Pacific Northwest National Laboratory, Verizon Enterprise Solutions and Carnegie Mellon and key representatives from other National Labs, industry, academia, propose to host three dialogues, each with 30-40 experts, focused on the challenges and cybersecurity coordination required in each of the following areas:

- *Industry* – examining both the role of the private sector in U.S. critical infrastructure, the differences in priorities across various sectors, and U.S. industry reliance on critical infrastructure operations.
- *Government* – examining the role of government in bridging the gap with private industry, encouraging appropriate information sharing, and modeling their correct role(s) and responsibilities in the innovation cycle.
- *Military* – with specific focus on the domestic critical infrastructure dependence and challenges in cybersecurity collaboration with OGA and the private sector; along with a unified concept of operations and cybersecurity coordination (detection through response).

Crosscutting Themes

In each of the planned dialogues a series of inter-related topics will be explored. These topics not only have direct correlation to the cybersecurity challenges in U.S. critical infrastructure protection, but without a clear doctrine to drive U.S. action the isolated improvements in one area may have minimal effect nationally. The themes we will explore include:

Cyber-physical Systems

Cyber-Physical Systems (CPS) are smart, networked systems with embedded sensors, processors, and actuators designed to sense and interact with the users and support real-time, guaranteed performance in safety-critical applications. CPS systems are an increasing part of all national critical infrastructures, finding new applications of CPS technology to improve everyday life and even transforming views of a society and community. A 2014 NSTCA report projected a staggering 26-

to-50 billion cyber-physical devices will be deployed in manufacturing, business, and home applications by 2020.

Cyber-physical systems use dedicated communication channels to enable remote control of large industrial and manufacturing equipment such electrical generators and power transmission and distribution. These early systems were very specialized proprietary systems, separated from the Internet and its risks. The economic advantages of the Internet and increasing functionality of commodity networking and information technology, however, have incentivized the re-architecting of these systems, leading to new cybersecurity risks that now affect the safety and availability of the services provided by critical infrastructures. The threats include purposefully coordinated existential threats to national critical infrastructures. Cybersecurity will be a daunting challenge at this unprecedented scale with billions of unprotected low-end commodity networked devices in many diverse applications.

The Innovation Cycle

Sound cybersecurity research must have a basis in controlled and well-executed experiments with operational relevance and realism. That requires tools and test environments that provide access to datasets at the right scale and fidelity, ensure integrity of the experimental process and support a broad range of interactions, analysis and validation methods. Efforts to ground the research and provide protections to those organizations that voluntarily share their sensitive data with researchers remain problematic.

A well-articulated, coordinated process that transitions research discoveries into practice is essential to ensure high-impact federal cybersecurity R&D. The research community, which focuses on developing and demonstrating novel and innovative technologies, and the operational community, which needs to integrate solutions into existing industry products and services, are not always aligned. An effective technology transfer program must be an integral part of our national strategy and rely on sustained and significant public-private participation.

Workforce Development

The Quadrennial Review highlights workforce development as an area of required focus in order to protect critical infrastructure, such as the energy grid, from cyber-attacks. Given the increasing role technology plays in our critical infrastructure, it is vitally important that our nation has an adequate, viable cybersecurity workforce to ensure the security of our critical infrastructure, but also to address a myriad of national security and domestic issues.

This is a multi-dimensional challenge requiring concerted effort across many areas in which academia, national labs, and the government all must play a role. The race to respond to cyber workforce needs has led to inconsistency in program quality and stove piping of expertise. There is a need for consistent, high-quality cybersecurity curricula that is integrated with science and engineering programs at all levels in the university system and continual education and training exercises given the fast-moving nature of cybersecurity, as well as availability of practical training opportunities and outside-the-classroom activities that provide real-work experience.

Unified Concept of Operations

Recent data breaches suffered by companies including JPMorgan Chase, FedEx, Target, Sony, and health insurer Anthem – have spurred past Presidential action to call for stricter cybersecurity measures, including higher legal penalties for hackers and legislation that would facilitate better sharing of threat information between companies and government. Examples of both good and poor collaboration between government and industry post an attack exist, but efforts to date have left most companies uncertain about the best way to engage government, who to engage, how far to extend trust, and where the cyber risk management becomes an individual corporate issue vs. a national issue.

While the National Institute for Standards and Technology published a Framework for Improving Critical Infrastructure Cybersecurity in 2016,[2] there is currently no proven and adopted framework for U.S. industry and government in the event of cyber-attack on one or more corporate entities.

Information Sharing

One of the key findings from the 2013 PCAST cybersecurity report was the need to improve government in industry's capacity to respond, in real time, to cyber threats by sharing data on these threats more extensively—in appropriate circumstances and with publicly understood interfaces—between private-sector entities and Government. The importance of information sharing for critical infrastructure was also highlighted in PPD-21, and the Administration has encouraged legislative initiatives to address information sharing in all sectors.

But while pockets of excellence exist in effective information sharing and collaboration between industry and government (e.g. CRISP in the electrical sector), the expansion to and adoption by other critical infrastructures has been far too slow. Where scalable models exist, and have been proven over years of usage, there is a need for broader application and better definition of the role of the government in

[2] https://www.nist.gov/sites/default/files/documents/cyberframework/Cybersecurity-Framework-for-FCSM-Jan-2016.pdf

encouraging and incentivizing scale-up and of industry's role in prioritizing and organizing for success. While President Trump's recent executive order seeks to protect critical infrastructure from cyber attacks by mandating a top-down review of cybersecurity and holds agencies accountable for safeguarding digital information,[3] there still lacks a mechanism for communication across different agencies and sectors.

Valuation of Cyber Security and Best Practices

Traditionally, cyber defenses and practices have been viewed as a cost that must be balanced against a risk that is being mitigated. This has led to a risk-based approach to identifying cyber vulnerabilities and threats that warrant the associated investment. This approach can lead stewards and owners of critical infrastructure to opt out of cyber defenses and best practices they view as cost-prohibitive given an assumption of likelihood or threat of cyber attack. This approach has proven to be costly when breaches occur. According to IBM's 2016 Cost of Data Breach Study, the total average cost of data break incidents for U.S. companies is $7.01 million, up from $6.53 million in 2015.[4]

If instead of viewing cyber technologies and practices through the lens of cost and benefit they were treated and valued as capital, owners and operators of critical infrastructure might arrive at very different priorities for investing in state of the art cyber capabilities. Providing a model for valuation of cyber security and best practices would require input from a diverse group that includes owners, operators and stewards of critical infrastructure, government regulators and oversight representatives, consumers of critical infrastructure services and products, the R&D and engineering community tasked with innovating in this area, and military and other representatives tasked with defending the infrastructure outside a profit motive.

Outcomes

The findings and recommendations around the six key themes garnered from each of the three dialogues will be synthesized into a national agenda articulating a policy doctrine on American cybersecurity.

From that doctrine, we will identify the "tent pole" actions that must be taken by specific organizations to meet the challenges and capitalize on the opportunities presented in the doctrine.

This doctrine will be shared widely with Congress, the Administration industry leaders and academia to drive action and protect American interests from the growing threat of cyber attack.

[3] https://www.whitehouse.gov/the-press-office/2017/05/11/presidential-executive-order-strengthening-cybersecurity-federal
[4] https://www-01.ibm.com/common/ssi/cgi-bin/ssialias?htmlfid=SEL03094USEN

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June 19, 2018
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The CHAIRMAN. Thank you for that. We look forward to that report.

Mr. Faison, it is wonderful to have you before the Committee.

STATEMENT OF JAY FAISON, FOUNDER, CLEARPATH

Mr. FAISON. Thank you. Good morning, Chairman Murkowski, Ranking Member Manchin, and other members of the Committee.

My name is Jay Faison. I'm the founder of ClearPath. ClearPath is a 501(c)(3) organization that develops and advances conservative clean-energy policies. I started ClearPath because I thought our national energy policy debate had become "drill, baby, drill" versus "keep it in the ground," and I thought there might be a better way.

I found the 2018 National Climate Assessment deeply sobering. Forest fires are one example. On average, the annual amount of area burned has increased fourfold in the last 30 years. PG&E, one of the nation's largest utilities, has declared bankruptcy as a result of their liability for recent fires. DoD's report on a changing climate released last month showed that 53 of the 79 military installations studied in the report are currently affected by floods and other impacts.

Given the risks of climate change, what could be a bigger priority for DOE's national energy laboratories than developing the next generation of affordable clean-energy technologies?

Heavy industry is now responding. Most major utilities have ambitious emission reductions goals. Senior executives from Southern, Shell and BP are beginning to link future bonuses to emissions targets. These actions make it clear that large energy companies understand that a low-carbon energy future is inevitable.

Some would argue that we have the technologies that we need to solve for climate change. First, it's important to recognize that a molecule of CO_2 emitted on the other side of the world has the same impact as one emitted here. Since 2000, coal-power generation in China has nearly quadrupled. Bloomberg reports that China's plans for new coal plants roughly equal the size of the entire U.S. coal fleet. Abroad, China is financing another 100 gigawatts of coal in at least 27 other countries.

So we have a choice. We can bet that the Chinese and Indians will close recently-built plants at the expense of economic growth or we can develop, demonstrate and export U.S.-based emission control technology.

Second, we should not put all of our eggs into one basket of technologies. It is unknown how far batteries and other forms of storage can fill in for renewables when the sun isn't shining and the wind isn't blowing. This is where the Department of Energy comes in. Many people are well aware of the Sunshine Initiative launched eight years ago. It set ambitious cost-reduction targets for solar panels for the year 2020 and achieved its goals three years ahead of schedule.

Most people are not aware of how DOE made the shale gas revolution possible. Decades of R&D coupled with a $10 billion alternative-production tax credit yielded breakthroughs in horizontal drilling, combined cycle turbines, diamond drill bits and 3D imaging that resulted in a 28 percent emissions decline. That same ingenuity that produced the shale boom can make gas fully clean.

Last May, a company called NetPower successfully demonstrated a zero-emission natural gas technology that could transform the global energy sector. This new technology could capture all of its emissions at effectively zero cost.

ARPA-E and Bill Gates-backed QuidNet is developing long duration storage solutions that could expand renewables. NuScale, a next-generation nuclear technology, could have demonstration reactors operational at Idaho National Lab in three to four years. These are the type of programs that will make a big dent in this enormous global problem.

The last Congress accomplished more in clean tech innovations than people think. Successes include incentives for carbon capture, renewables, and advanced nuclear; record investments in R&D and streamlined permitting for advanced nuclear and hydropower.

But what exactly are we shooting for? What does success look like? I'm a strong advocate for big, ambitious goals that deliver a full toolbox of clean and affordable energy solutions, smart investments in moonshot goal programs that deliver low cost, high performing, clean technology from basic research all the way through demonstration. Let's create stronger financing incentives to commercialized cutting-edge companies and deploy these technologies globally. Let's streamline regulation to get clean energy online quickly.

Ambitious bipartisan cooperation on innovation is essential and attainable. In fact, it is the only chance our nation will have if it's going to play a significant role in the global solution.

Thank you again for this opportunity, and I look forward to the discussion.

[The prepared statement of Mr. Faison follows:]

Jay Faison
Founder, ClearPath
Testimony before the Senate Energy and Natural Resources Committee
Hearing on "The State of Clean Energy Innovation"

Good morning Chairman Murkowski, Ranking Member Manchin and other members of the committee. My name is Jay Faison, and I am the Founder of ClearPath. ClearPath is a 501(c)3 organization that develops and advances conservative policies that accelerate clean energy innovation. We support solutions to unlock breakthroughs in lower-carbon technologies - including next-generation energy storage, nuclear, hydropower, and carbon capture from both coal and natural gas. I started ClearPath because I thought our national energy policy debate had become polarized between 100% renewables and "drill baby drill" - I knew there had to be a smarter middle path for both our climate and our economy.

I found the 2018 National Climate Assessment deeply sobering. Forest fires are one example the report highlights. On average, the annual amount of area burned has increased fourfold in the last 30 years.[1] Of the 10 most destructive wildfires in California's history, seven have occurred since 2015.[2] California's "Camp Fire", the deadliest in the state's history, killed over 85 people and did $16.5 billion in damage.[3] PG&E, one of the nation's largest utilities, has declared bankruptcy as a result of their liability for recent fires. Given the risks of climate change, what could be a bigger priority for DOE's national energy laboratories than developing the next generation of affordable clean energy technologies?

Heavy industry is now responding. Southern Company is reducing their emissions in half by 2030 and will be low to no carbon by 2050 - all while rapidly innovating clean tech. Shell also aims to cut its carbon emissions in half by 2050. Notably, senior executives from Southern, Shell, BP are among the growing list of big energy companies who are beginning to link future bonuses and other pay to their emission targets. These actions make it clear that large energy companies understand that a low carbon future is inevitable.

Some would argue that we have the technologies that we need to solve for climate change. If that was the case, we would not be as concerned about climate change as

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[1] https://nca2018.globalchange.gov/chapter/6/
[2] http://www.fire.ca.gov/communications/downloads/fact_sheets/Top20_Destruction.pdf
[3] https://en.wikipedia.org/wiki/Camp_Fire_(2018)

we are today because the solution would be clear, imminent and deployable. Unfortunately, that's not the situation we face.

First, it is important to recognized that a molecule of CO2 emitted on the other side of the world has the same impact as one released here. Since 2000, coal power generation in China nearly quadrupled.[4] Bloomberg reports that over 250 gigawatts of new Chinese coal capacity remain planned, roughly the size of the entire U.S. coal fleet. [5] Abroad, China is financing another 100 gigawatts of coal in at least 27 countries.[6] The expected emissions *growth* from developing Asian countries alone would offset a complete decarbonization of the U.S. economy by mid-century.[7] We have a choice - bet that Chinese and Indians will close these recently built plants at the expense of economic growth; or develop, demonstrate and export U.S.-based emission control technology.

Second, we should not put our eggs into one basket of technologies. It is unknown how far batteries and other forms of storage can fill in for renewables when the sun isn't shining or the wind isn't blowing. This is where the Department of Energy comes in. Many people are well aware of the SunShot Initiative launched 8 years ago. It set ambitious cost-reduction targets for solar panels for the year 2020 and achieved their goals three years ahead of schedule.

Most people are not aware of how DOE made the shale gas revolution possible with decades of public-private research partnerships.[8] This R&D, coupled with a $10B alternative production tax credit, yielded breakthroughs in combined cycle turbines, diamond drill bits, horizontal drilling and 3D imaging.[9] This market-driven phenomenon has increased natural gas from 19 to 32% of the grid[10] between 2005 and 2017, resulting in a 28% emissions decline.[11]

The same ingenuity that produced the shale boom can make that gas fully clean. Last May, a company called NETPower, a joint venture between 8 Rivers, Exelon,

[4] https://www.shell.com/energy-and-innovation/the-energy-future/scenarios/shell-scenario-sky.html
[5] https://www.bloomberg.com/news/articles/2018-11-30/almost-half-of-coal-power-plants-seen-unprofitable-to-operate
[6] http://ieefa.org/wp-content/uploads/2019/01/China-at-a-Crossroads_January-2019.pdf
[7] https://www.eia.gov/outlooks/aeo/data/browser/#/?id=10-IEO2017&region=0-0&cases=Reference&start=2010&end=2050&f=A&linechart=Reference-d082317.3-10-IEO2017~~~~~~~Reference-d082317.17-10-IEO2017&map=&ctype=linechart&sourcekey=0
[8] https://static.clearpath.org/2019/02/shale-gas-fracking-doc.pdf
[9] http://americanenergyinnovation.org/wp-content/uploads/2013/03/Case-Unconventional-Gas.pdf
[10] https://www.eia.gov/survey/#eia-923
[11] https://www.eia.gov/environment/emissions/carbon/

Occidental Petroleum, and McDermott, successfully demonstrated a zero emission natural gas technology that could transform the global energy sector. Unlike traditional carbon capture, this new technology could capture all its emissions effectively at zero extra cost. More broadly, it's an immensely promising time for U.S. clean innovation. Public-private efforts like the ARPA-E and Bill Gates-backed QuidNet are developing innovative long-duration storage solutions that could expand renewables. QuidNet's energy storage could be deployed nearly anywhere by pumping and compressing water into depleted oil wells and harnessing the energy when it decompresses. Entrepreneurs are innovating small modular nuclear reactors and micro-reactors, in partnership with our national labs, that are less capital intensive and more flexible to work alongside renewables. NuScale, which submitted the first small modular reactor design for Nuclear Regulatory Commission review, is steadily progressing toward certification and could have demonstration reactors operational at Idaho National Lab in three years. Those building even more scalable and affordable microreactors will follow in NuScale's footsteps and start submitting licensing applications to the NRC as early as this year.

These efforts are representative of the aggressive public-private collaborations needed to dent this global problem.

The last Congress hasn't received the credit its due for boosting low-carbon technologies. Your broadly bipartisan agenda enhanced critical incentives for carbon capture, renewables, and advanced nuclear; invested in Department of Energy R&D at record levels; and reformed regulations to accelerate the licensing of advanced nuclear and hydropower.

But what exactly are we shooting for? What does success look like? Our nation's best scientists have been very clear about the answer to these risks - the solution must include greatly scaling up all of the low carbon technologies at our disposal, from more renewables to nuclear energy to carbon capture. I am a strong advocate for big ambitious goals that deliver a full tool box of clean and affordable energy solutions. Smart investments in "moonshot" goal programs that deliver low-cost, high-performing clean technology - from basic research all the way through demonstrations - are essential. Let's create stronger financing and incentives to commercialize cutting-edge companies and deploy those technologies globally. And let's enact deep regulatory reforms that remove barriers to rapidly scaling clean technology.

Bipartisan cooperation on clean energy innovation to address climate change is essential under divided government - and attainable. In fact, it is the only chance our nation will have if it is going to play a significant role in the global solution. Thank you again for this opportunity, and I look forward to the discussion.

The CHAIRMAN. Thank you so much for your contribution.
Mr. Grumet, welcome.

STATEMENT OF JASON GRUMET, PRESIDENT, BIPARTISAN POLICY CENTER

Mr. GRUMET. Thank you, Chairman Murkowski and Ranking Member Manchin and the entire Committee, for the privilege of being with you today as you start to think about the ambitious agenda I know you have for the next two years.

I have burdened your staff with lengthy testimony that I will summarize in two overarching points. The first is that public and private investment is needed to sustain our remarkable energy dominance that the United States has achieved in the last few years, and the second point is that until we establish a shared national purpose and goal our innovation policy will lack the ambition and the resolve that are necessary for ultimate success.

While a lot of the focus today is going to be on breakthroughs, I think we also have to recognize the importance of supporting near-term critical investments to improve the efficiency, the safety and the performance of our existing oil, gas, nuclear, coal, and renewable resources as well as our investments in grid and pipeline infrastructure. These are the components that are going to be necessary to sustain our current economic might and in fact buy the time we need for our innovation agenda to succeed.

There are a lot of ideas in my testimony. I will just note two that I think that are particularly important to frame the debate, and the first is the core idea of the American Energy Innovation Council which in 2010 argued that we must triple our energy investment from roughly $5 to $15 billion a year. I recognize that that is a lot of money; but as Norm Augustine, one of our committee members and truly a former rocket scientist, likes to remind us, if your airplane is burdened, you don't drop weight by losing the engines. This is something the nation needs to do for our future.

Second, we must design all of our policies, our investments, our incentives and our requirements, to encourage all forms of noncarbon energy. Recent efforts like the Clean Energy for America Act and state efforts in New York, California, and New Jersey are really good steps in this direction.

I now want to turn to this broader question of national purpose. In my opinion, effective innovation requires clear, realistic national goals, a relatively stable policy environment, and a culture that is resilient to occasional failure. These are not easy conditions to meet in a competitive and closely divided democracy and they are almost impossible to achieve if this Committee and this Congress does not in fact come together around a broad and shared idea. It's remarkable what our nation can achieve when we have that kind of commitment.

And while the analogy to moonshot may be overused, an aspect of it is also overlooked, and that is that before our space program was a historic success, it suffered horrific failures. January 27th, 1967, six years into the space program, a fire erupted on the launch pad killing astronauts Gus Grissom, Ed White and Roger Chaffee. Congress didn't turn on itself. It didn't restrict NASA funding or filibuster budgets. The country came together; 18

months later, we held our breath and three astronauts were put into space; and 10 months later, Neil Armstrong set foot on the moon.

It is an understatement to acknowledge that we do not have a similar consensus in this Congress on energy and climate policy. I think there's broad support for promoting security, I think there's broad support for competitiveness, but the absence of a shared vision about whether and how to address climate change remains an intractable barrier to an effective policy.

I firmly believe the U.S. must achieve net zero carbon emissions by midcentury, but I reject the notion that we can accelerate the future by messing up the present. After a decade of what I honestly believe has been reckless debate about the existence of the climate problem, we simply do not have time for a fact-free debate about the solution. What I think we need is a "Green True Deal" anchored in innovation that embraces all non-carbon sources and is designed to cushion the economic impacts and dislocations that are inevitable during the transition to a low-carbon economy.

I see five broad pathways that can move us in this direction: advanced energy storage, advanced nuclear power, carbon capture and utilization, and storage for coal and gas, low-carbon transportation fuels, and, finally, direct air capture technologies that remove carbon from the air. This is an issue that I think needs more discussion, and the Bipartisan Policy Center is very focused on the potentials around direct air capture.

If none of these technologies are price competitive and massively deployed in the next 30 years, I am not optimistic about the future. If all are successfully commercialized, we will dramatically strengthen the U.S. economy and literally save the world. With some reasonable combination of success and failure, I think we can actually provide a better future for our children, which actually has been the human tradition for 10,000 generations.

So I want to close where I began. Federal energy innovation investments are providing valuable economic and environmental benefits, but it is simply not possible to design a coherent energy policy by triangulating the vast and empty space between the Administration's resistance to acknowledge the climate problem and new progressive demands to solve it through renewable power in ten years.

I know that no one on this panel wants to impose economic hardship on millions of Americans, and no one on the panel wants to condemn future generations to diminished opportunity or reduced quality of life. If you'll permit me as the clock winds down with just one personal reflection, I can't be in this room and not think of my friend Senator Pete Domenici who worked at the Bipartisan Policy Center until he passed away about 18 months ago. And I think everyone on this Committee remembers in 2005 and 2007 what Senator Domenici and Senator Bingaman did when they traded the gavel back and forth and passed remarkable legislation that set the stage for the renewable progress the energy efficiency, and the remarkable production that now makes us an energy exporter.

And Senator Murkowski, I think you'll agree that when you think back, that was not a Committee of gentle souls. It was a group that had strong partisan disagreements. And when I think about Senators Domenici and Bingaman and I'm looking at Sam, I remember them having two things in common: they cared about facts and they happened to be from New Mexico. But they were about, because they cared about facts, to actually sustain huge battles that were anchored in evidence and fundamentally in friendship.

And I think it is in this tradition, if this Committee can lead a national debate where both the climate problem and the potential solutions are grounded in science and engineering and economics, I am confident that American innovation will do the rest.

It is a privilege to be with you, and the Bipartisan Policy Center hopes that we can help as you move forward with this agenda.

[The prepared statement of Mr. Grumet follows:]

BIPARTISAN POLICY CENTER

Written Testimony
Jason Grumet
President, Bipartisan Policy Center

Before the United States Senate Committee on Energy and Natural Resources
February 7th, 2019

Chairman Murkowski, Ranking Member Manchin, and members of the Committee, thank you for the opportunity to join this critical discussion on the key role of innovation in our energy and economic future.

My testimony will focus on the imperative to raise our nation's ambition and commitment to energy innovation, and how this Committee can help overcome political obstacles to ensure an effective innovation agenda.

Propelling Economic Growth

Innovation is the core of America's economic strength and future prosperity. Indeed, at least 50 percent of the nation's annual GDP growth can be traced to increases in innovation.[1] While our nation must substantially increase its commitment and ambition to energy innovation, we have a sound foundation to build upon. Much of the energy abundance we enjoy today can be traced to our nation's unparalleled research and development (R&D) infrastructure. Today's shale gas boom can trace its history to industry-led research and demonstration initiatives funded by the U.S. Department of Energy (DOE), such as seismic mapping, horizontal drilling, and advanced drill bit technology developed during the 1970s. R&D carried out at the National Renewable Energy Laboratory (NREL) has enabled wind and solar energy production to quadruple[2] over the past decade while costs for these technologies have been cut nearly in half. Building on basic and applied atomic research conducted during the Manhattan

[1] Recognizing the importance of energy innovation to long-term economic growth and competitiveness, BPC convened a group of top business leaders who formed the American Energy Innovation Council (AEIC) (http://americanenergyinnovation.org/) in 2010 to support strong federal investments in energy R&D. The Council has published numerous reports, white papers, and case studies demonstrating these connections, and is in firm agreement that targeted and increased federal investments in energy R&D are crucial to bolstering America's long-term economic health and competitiveness.

[2] U.S. Energy Information Administration. "Electric Power Monthly – Table 1.1.A. Net Generation from Renewable Sources: Total (All Sectors), 2008 – May 2018." July 2018. Available at: https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_1_01_a

Project, the U.S. government began developing peaceful applications of nuclear technology following the end of World War II. The federal government built the first nuclear reactor[3] in the 1950s before transferring the commercial development of the technology to the private sector—and in doing so laid the bedrock for the modern nuclear energy industry, which contributed $60 billion[4] to U.S. GDP in 2015 and today supplies one-fifth of U.S. electricity and nearly three-fifths[5] of America's carbon-free electricity.

In addition to these often-cited marquee achievements, there is an ongoing and important role for public and private collaboration to improve the performance of our nation's energy systems. I have the privilege of serving on the National Petroleum Council (NPC) study on Oil and Gas Transportation Infrastructure.[6] Part of our focus is on how advances and deployment of new technology can improve the safety and environmental performance of our country's existing and future oil and gas infrastructure. Cooperation between public and private resources will be essential for all stages of deployment, from basic research to updating regulations to incorporate new methods of compliance. I hope this Committee will make time to explore the NPC conclusions when they are finalized in October. Corporations also can help advance innovative energy technologies through corporate power procurement practices. We have seen great success in business's ability to spur the development of renewables through power purchase agreements. We are now seeing businesses, such as Google, beginning to explore how to build on this successful model to procure 24/7 clean energy.[7]

Federal investment in energy R&D has a high return on investment. Recently, DOE found that federal investments in building efficiency R&D from 1976 to 2015 yielded energy savings of nearly $22 billion[8]

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[3] Mark Berkman and Dean Murphy. "The Nuclear Industry's Contribution to the U.S. Economy." The Brattle Group. July 2015. Available at http://files.brattle.com/files/7629_the_nuclear_industry's_contribution_to_the_u.s._economy.pdf.
[4] U.S. Energy Information Administration. "What is U.S. Electricity Generation by Energy Source?" Updated March 7, 2018. Available at: https://www.eia.gov/tools/faqs/faq.php?id=427&t=3.

[5] U.S. Energy Information Administration. "U.S. Energy-Related Carbon Dioxide Emissions, 2016." October 2017. Available at: https://www.eia.gov/environment/emissions/carbon/.

[6] National Petroleum Council. "Energy Secretary Requests National Petroleum Council Advice on Two Major Topics." Press Release, September 27, 2017. Available at: https://www.npc.org/NPC-press_release-127th_mtg-092717.pdf

[7] Google. "Moving toward 24x7 Carbon-Free Energy at Google Data Centers: Progress and Insights." October, 2018. Available at: https://static.googleusercontent.com/media/www.google.com/en//green/pdf/achieving-100-renewable-energy-purchasing-goal.pdf

[8] Department of Energy. "Benefit-Cost Evaluation of U.S. Department of Energy Investment in HVAC, Water Heating, and Appliance Technologies." September 2017. Available at: https://www.energy.gov/sites/prod/files/2017/09/f36/DOE-EERE-BTO-HVAC_Water%20Heating_Appliances%202017%20Impact%20Evaluation%20Final.pdf

for consumers, achieving a benefit-to-cost ratio from 20-to-1 to 66-to-1. Similarly, public investments in high-efficiency diesel engines of $931 million between 1986 and 2007 were shown to generate $70 billion[9] in economic benefits, a return of $70 for every federal dollar invested. The National Academies of Science, Engineering, and Medicine found that DOE investments in energy efficiency R&D between 1978 and 2000 generated a return of roughly $20 for every dollar invested[10], while fossil energy R&D programs between 1986 and 2000 received $4.5 billion in funding but generated $7.4 billion[11] in economic benefits to the United States.

Late-stage R&D initiatives funded by DOE have also generated significant benefits to the United States. Seventy-five percent[12] of domestic coal-fired power plants employ technology with roots in DOE's Clean Coal Technology Demonstration program and the newly operational Petra Nova[13] carbon capture project in Texas was given critical support through a grant from DOE's Clean Coal Power Initiative. In addition, late-stage research and testing supported by DOE has continued to drive down the costs of deployed renewable energy technologies to make them cost-competitive with incumbent generation technologies.

Fostering International Competitiveness
Increased public and private commitment to energy innovation is needed if we are to sustain U.S. global energy dominance. Due to the remarkable technological advances in oil and gas production, the United States will become a net energy exporter next year.[14] Total energy investment worldwide was over $1.7 trillion[15] in 2016, accounting for 2.2 percent of global GDP. The United States must strive to

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[9] Jeffrey Rissman and Hallie Kennan. "Case Study: Advanced Diesel Engines." American Energy Innovation Council. March 2013. Available at: http://bpcaeic.wpengine.com/wp-content/uploads/2013/03/Case-Diesel-Engines.pdf

[10] National Academy of Science. "Energy Research at DOE: Was it Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000." 2001. Available at: http://www.nap.edu/download/10165

[11] Ibid.

[12] Department of Energy. "Fossil Energy Research Benefits." Accessed August 18, 2018. Available at: https://www.energy.gov/sites/prod/files/cct_factcard.pdf

[13] Department of Energy. "Clean Coal Power Initiative." Accessed August 18, 2018. Available at: https://www.netl.doe.gov/research/coal/large-scale-demonstrations/clean-coal-power-initiative

[14] U.S. Energy Information Administration. "Annual Energy Outlook 2019." January 2019. Available at: https://www.eia.gov/outlooks/aeo/

[15] International Energy Agency. "World Energy Investment 2017." July 2017. Available at: https://www.iea.org/publications/wei2017/

achieve a similarly dominant position in developing and exporting the efficient, and lower-carbon energy technologies required to meet the world's growing demand for clean energy.

China has become one of the largest[16] spenders on energy R&D as a share of GDP, and the United States now trails 12 other nations in the amount of public dollars invested in energy R&D relative to GDP. In our market economy, decisions to develop and commercialize new technologies must be driven by corporations deploying private capital. However, it must be recognized that the energy sector is uniquely challenged by the high costs of technology development and the difficulty companies face in recouping these investments directly or quickly. This dynamic is revealed in the fact that private energy sector R&D investments are just 0.3 percent[17] of revenues, compared to nearly 20 percent in pharmaceuticals,[18] 10.6 percent in electronics, and 7.6 percent in aerospace.[19] To compete in the global marketplace, U.S. technology policy must combine increased direct federal investment and incentives to encourage and reward private resource commitments.

Confronting Climate Change

The country needs a "Green True Deal," one that is anchored in innovation and designed to cushion the economic impacts and worker dislocations that are inevitable in the transition to a low-carbon economy.[20] Recent domestic[21] and international[22] assessments of climate change reinforce three fundamental findings:

[16] International Energy Agency. "World Energy Investment 2017." July 2017. Available at: https://www.iea.org/publications/wei2017/

[17] Industrial Research Institute. "2016 Global R&D Funding Forecast." 2016. Available at: https://www.iriweb.org/sites/default/files/2016GlobalR%26DFundingForecast_2.pdf

[18] PhRMA. "2018 PhRMA Annual Membership Survey." July 2018. Available at: http://phrma-docs.phrma.org/sites/default/files/pdf/biopharmaceutical-industry-profile.pdf

[19] National Science Foundation. "Science & Engineering Indicators 2018." January 2018. Available at: https://www.nsf.gov/statistics/2016/nsb20161/uploads/1/nsb20161.pdf

[20] Jason Grumet. "It's time for a Green 'True' Deal." Roll Call, February 4th, 2019. Available at: http://www.rollcall.com/news/opinion/time-green-true-deal-progressive-environment-climate-change

[21] U.S. Global Change Research Program. "Fourth National Climate Assessment." November 2018. Available at: https://nca2018.globalchange.gov/

[22] United Nations Intergovernmental Panel on Climate Change (IPCC). *Special Report: Global Warming of 1.5C.* 2018. https://www.ipcc.ch/sr15/

1. On the current trajectory, climate change will create unacceptable economic and social costs in the United States and around the globe.
2. The United States and other developed nations must achieve net-zero carbon emissions by mid-century to avoid the worst effects of climate change.
3. We do not presently have the technological capacity to decarbonize the domestic or global economy in this timeframe.

Over the next 20 years, global energy demand is projected to rise by 30 percent.[23] Across the globe today, there are as many people who lack access to electricity as there were when Edison commercialized the light bulb in 1882. The solution to climate change must accommodate the reality that billions of additional people must be provided with access to affordable and reliable energy services while we simultaneously eliminate carbon from the energy sector.

Here in the United States, millions of Americans' livelihoods and the economies of thousands of communities are directly linked to existing energy production. Moreover, millions of Americans are living paycheck to paycheck and do not have the luxury of buying a Tesla charged by community-solar microgrids. The hard truth is that proposals to achieve near-term decarbonization with existing technology—like moving to a fossil fuel free economy in the next 10 years—are technologically and economically infeasible. While presumably well-intended, these proposals distract from the evidence-based debate that is the predicate for real progress. The stakes are very high. Failure to decarbonize our energy system over the next 30 years will impose profound economic and social disruption on the next generation. We have no time to waste.

No one on this panel wants to impose economic hardship on millions of Americans today and no one on this panel wants to condemn future generations to diminished opportunity and reduced quality of life. The question then is this: What is preventing us from unleashing the awesome power of American ingenuity to create economically viable low-carbon energy solutions?

Overcoming Political Barriers to Innovation

Effective innovation requires clear and realistic national goals, a relatively stable policy environment, and a culture that is resilient against occasional failure. These conditions are not easily established in a closely divided democracy, and they are almost impossible to achieve when the Congress is not broadly united in a shared purpose.

[23] International Energy Agency. "World Energy Outlook 2017." November 2017. Available at: https://www.iea.org/weo2017/

The obligation to engage minority views and the commitment to value nation above party are historic strengths of our political system. These foundational features have led to national consensus and resilient public policy. It is remarkable what our nation has achieved when we commit to a broadly shared goal. The analogy to the moonshot is overused, but there is one insight that is often overlooked. Before our space program was a historic success, it suffered horrific failures. On January 27, 1967—six years into the space program—a fire erupted on the launch pad, killing astronauts Gus Grissom, Ed White, and Roger Chaffee. Our Congress did not turn on itself, restrict NASA program funding, or filibuster budgets. Instead, 18 months later, we held our breath and sent three more astronauts into space. Ten months after that, Neil Armstrong set foot on the moon.

Congress should never tolerate mismanagement in our innovation programs and must be vigilant to ensure that DOE is well-designed for success. But our nation cannot achieve great things absent a shared sense of purpose that carries us through when the going gets tough. While there is broad bipartisan support in Congress for promoting energy security and economic competitiveness, the absence of any shared vision about whether and how to address climate change is an intractable barrier to effective energy innovation policy.

Recent technical analysis by the Intergovernmental Panel on Climate Change and others has helped to reveal the urgency of the climate challenge, the inadequacy of existing solutions, and the need to prioritize substance and science over cultural preferences on the left and right. This Committee has an opportunity to take a critical step forward by clearly rejecting the false arguments that continue to feed division and dysfunction in our energy policy. If this Committee could agree that climate change is a critical challenge and agree that we cannot eliminate fossil fuels or achieve 100 percent renewable power in the next decade, it could then begin to develop a truly effective innovation agenda.

As a next step, the Committee should establish some clear and compelling goals. I do not pretend to know precisely what they are, but to my mind there are five technology pathways that have the potential to reconcile our economic and ecological imperatives. They are: 1) advanced energy storage; 2) advanced nuclear power; 3) carbon capture, utilization, and storage for coal and natural gas; 4) low-carbon transportation fuels, such as hydrogen and electrification; and 5) direct air capture technologies that remove carbon dioxide from the ambient air.[24] If none of these technologies are price competitive

[24] Carbon removal is a promising breakthrough technology where greater research and development is needed. Carbon removal encompasses a suite of land-based and technological approaches that remove already-emitted carbon dioxide directly from the atmosphere. Importantly, all pathways that limit warming to 1.5 degrees Celsius in the IPCC Special Report rely on some form of carbon removal. The 2018 National Academies report on negative emission technologies agrees that fundamentally new carbon removal options

and massively deployed in the next 30 years, I am not optimistic about the future. If all are successfully commercialized, we will dramatically strengthen our economy while literally saving the world. With some reasonable combination of success and failure, I am confident that we can provide a better future for our children, which has been our tradition for the past 10,000 generations.

As we strive to invent new technologies, it is essential that this Committee lead the Congress to recognize that we cannot accelerate the future by messing up the present. We must support the critical near-term investments in natural gas infrastructure, energy efficiency, renewables, and existing nuclear facilities—all of which are necessary to sustain our economic might and buy time for our innovation agenda to succeed.

The clean innovation agenda already enjoys considerable bipartisan support. Last year, Congress passed the Nuclear Energy Innovation Capabilities Act, which eliminates some of the financial and technological barriers standing in the way of nuclear innovation. Congress also examined the Nuclear

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will be needed to avert dangerous temperature rise and articulates the need for a multi-billion dollar federal R&D program across a portfolio of carbon removal technologies.

One of these approaches - direct air capture and storage - has nearly unlimited CO_2 removal capacity and is already operating successfully at pilot scale here in the United States. While a handful of companies around the world - including Carbon Engineering in Canada, Global Thermostat in the United States, and Climeworks in the European Union - have demonstrated that direct air capture technology works, efficiency and cost must be improved for it to be deployed more broadly.

In addition to carbon removal, carbon capture technology is successfully operating at pilot and commercial scales in the United States and around the world. The global carbon capture and storage market is predicted to nearly double between 2016 and 2022. The ability to sell or use CO_2 to make useful products makes the economics of these projects more appealing, and CO_2 is already considered a valuable commodity for certain uses. Today, CO_2 is used in enhanced oil recovery (EOR) and R&D is underway to produce stronger and lower-cost cement. Further, when coupled with sustainably produced hydrogen, synthetic fuels, chemicals, and plastics can be manufactured directly from captured CO_2. With these envisioned applications, the market for CO_2 is expected to grow. The recent expansion of the 45Q Carbon Capture Incentive, a federal tax credit for carbon capture and utilization projects in the United States, is expected to unleash $1 billion in investment over the next six years—a lucrative technology market where America can get ahead.

Further Reading on CDR and CCUS:

1. National Academy of Science. *Negative Emissions Technologies and Reliable Sequestration: A Research Agenda*. 2018. https://www.nap.edu/catalog/25259/negative-emissions-technologies-and-reliable-sequestration-a-research-agenda
2. National Academy of Science. *Gaseous Carbon Waste Streams Utilization: Status and Research Needs*. 2018. https://www.nap.edu/catalog/25232/gaseous-carbon-waste-streams-utilization-status-and-research-needs
3. United Nations Intergovernmental Panel on Climate Change (IPCC). *Special Report: Global Warming of 1.5C*. 2018. https://www.ipcc.ch/sr15/
4. Carbon180. *A Review of Global and U.S. Total Available Markets for Carbontech*. 2018. https://carbon180.org/carbontech-labs-reports

Energy Innovation Act; the ARPA-E Reauthorization Act; the Promoting Small Business Innovation through Partnerships with National Labs Act; the Fossil Energy R&D Act; the USE IT Act and others.

There are reasonable steps that Congress can take to build upon these early steps to establish an energy innovation portfolio that matches the scale of the climate challenge while opening new markets and protecting national security. Since 2010, the American Energy Innovation Council (AEIC), convened by BPC, argued that federal investment in energy innovation must be tripled from slightly more than $5 billion in 2010 to $16 billion by 2015. We have yet to hit that goal. A recent report from the AEIC, *Energy Innovation: Fueling America's Economic Engine*, proposes several other near-term steps to enhance federal innovation investment:

1. Fund DOE's Advanced Research Projects Agency-Energy (ARPA-E) at $1 billion per year. At a minimum, ARPA-E should receive $400 million per year in fiscal year (FY) 2020, a $34 million increase over FY 2019, which would allow one additional high-impact R&D program to be released by ARPA-E in that year.
2. Support and expand new and innovative institutional arrangements, such as energy innovation hubs, energy frontier research centers, the Manufacturing USA program, and the Energy Materials Network.
3. Make DOE work more efficiently —along the ARPA-E model where appropriate.
4. Establish a New Energy Challenge Program for high-impact pilot projects.
5. Establish regionally centered innovation programs.
6. Have the federal government support creative efforts to incentivize private-sector investment in energy R&D.

In addition to supporting innovation through R&D funding, Congress must also consider technology-neutral, performance-based policies that incentivize the deployment of all non-carbon energy sources. Legislation, such as the Clean Energy for America Act, that would provide equitable tax incentives for all non-carbon technologies is a step in the right direction. Even more significant would be an ambitious Zero Carbon Electricity Standard that in addition to supporting nuclear power, carbon capture, energy efficiency, and renewable wind and solar would include provisions to support innovative energy technologies and other first movers through benefit multipliers that sunset as an industry matures. While any mandate will be contentious, a consistent federal requirement for zero-carbon power would be far more effective than the current panoply of state renewable power mandates. But, lessons can be drawn from the states. Efforts in California, New Jersey, and New York to expand requirements to count all zero-carbon production offer a model for federal consideration.

We know that a mix of state and federal policies can be effective. The combination of incentives in PURPA, federal tax credits for wind and solar, procurement goals/mandates, Recovery Act provisions, and state renewable portfolio standards and tax incentives have spurred the private investment that has led to the boom in wind and solar deployment. Having achieved this success, Congress must now increase its ambition to support a competition among all sources of non-carbon energy production.

I would like to close by raising a difficult question for which I have no good answer. Will the United States continue to build and commercialize first-generation breakthrough energy technologies? While American innovation is alive and well in the software technology sector, where ingenuity and $1 million can create a new and valuable service, the energy technology sector innovates in billion dollar commitments to projects that take a decade or more from conception to completion. The financial and political risks inherent in these critical achievements are prohibitive for the private sector. We cannot accept a future in which all energy breakthroughs are commercialized in China or other centrally planned economies. The loan guarantee programs have been successful to a point, but we must entertain new approaches that share risks among the public and private sectors to enable our great nation to achieve great things.

Conclusion

Federal energy innovation investments are providing valuable economic and environmental benefits despite the lack of a meaningful consensus about program goals or future direction. There is broad support in Congress for energy security and economic competitiveness, but absent an informed, bipartisan consensus in favor of a real technology solution to a real climate problem, U.S. innovation efforts will fall far short. While success here may not capture the imagination of landing on the moon, the stakes are far greater. This Committee is the single best place in the U.S. government to rebuild an evidence-based approach to the climate and energy challenge. BPC stands ready to assist the Committee in any way we can.

Appendix

Further reading on the imperative for a technologically inclusive innovation agenda.

American Energy Innovation Council Reports

American Energy Innovation Council. "The Business Plan." 2010. http://americanenergyinnovation.org/2010/06/the-business-plan-2010/

American Energy Innovation Council. "Catalyzing Ingenuity." 2011. http://americanenergyinnovation.org/2011/09/catalyzing-ingenuity/

American Energy Innovation Council. "Restoring American Energy Innovation Leadership: Report Card, Challenges, and Opportunities." 2015. http://americanenergyinnovation.org/2015/02/restoring-american-energy-innovation-leadership-report-card-challenges-and-opportunities/

American Energy Innovation Council. "The Power of Innovation: Inventing the Future." 2017. http://americanenergyinnovation.org/2017/06/the-power-of-innovation-inventing-the-future/

American Energy Innovation Council. "Energy Innovation: Fueling America's Economic Engine." 2018. http://americanenergyinnovation.org/2018/11/energy-innovation-fueling-americas-economic-engine/

Importance of Firm Zero-Carbon Energy and Innovation

Jenkins, Jesse D., Max Luke, and Samuel Thernstrom. "Getting to Zero Carbon Emissions in the Electric Power Sector." *Joule* 2.12 (2018): 2498-2510. Available at: https://www.cell.com/action/showPdf?pii=S2542-4351%2818%2930562-2

Article summarizes forty recent studies addressing alternative pathways to deep decarbonization of power grids and concludes that the weight of the studies points to the conclusion that a diverse portfolio of zero carbon power options, including especially firm zero carbon energy, increases the chances of affordably meeting deep emission reduction targets.

Sepulveda, Nestor A., et al. "The role of firm low-carbon electricity resources in deep decarbonization of power generation." *Joule* 2.11 (2018): 2403-2420. Available at:

https://www.sciencedirect.com/science/article/pii/S2542435118303866

Article investigates the role of firm low-carbon resources in decarbonizing power generation in combination with renewable resources, electricity storage, demand response and long-distance transmission.

Intergovernmental Panel on Climate Change, "Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by governments" (2018) Available at: https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-special-report-on-global-warming-of-1-5c-approved-by-governments/

Scenarios for meeting 1.5 degree C target involved substantial increase in nuclear energy and carbon capture and storage as well as renewable energy.

Davis, Steven J., et al. "Net-zero emissions energy systems." *Science* 360.6396 (2018). Available at: https://energyinnovation.org/wp-content/uploads/2018/07/Davis-et-al_Science2018_net-zero-emissions-energy-with-Suppl.pdf

Examines challenge of decarbonizing some challenging energy services and industrial processes—such as long-distance freight transport, air travel, highly reliable electricity, and steel and cement manufacturing— concluding that "a range of existing technologies could meet future demands for these services and processes without net addition of CO_2 to the atmosphere, but their use may depend on a combination of cost reductions via research and innovation, as well as coordinated deployment and integration of operations across currently discrete energy industries."

The CHAIRMAN. Thank you. We appreciate that message and, again, the reminder of the leadership of Senator Domenici particularly when it came to what we refer to as a nuclear renaissance. He believed in it, and he advanced it in a significant way.

Your challenge to us is good and appreciated. We can have great debate about the matter of climate change. I have adopted a new phrase that was provided to me by one of our military leaders in Alaska. He says, "I'm not a scientist, but I am a master of the obvious."

Let's go to Mr. Wood.

STATEMENT OF JAMES F. WOOD, INTERIM DIRECTOR, ENERGY INSTITUTE, WEST VIRGINIA UNIVERSITY

Mr. WOOD. Chairwoman Murkowski, Ranking Member Manchin and members of the Committee, thank you for the opportunity to give testimony and to answer your questions.

The WVU Energy Institute serves to facilitate collaborative and innovative solutions for the energy future of West Virginia and the United States and also supports sponsored and grant-funded research programs and seeks ways to commercialize intellectual property at the university.

From 2009 to 2012, I was the Deputy Assistant Secretary for the Office of Clean Coal and Carbon Management in the U.S. Department of Energy's Office of Fossil Energy. In that position, I was responsible for the agency's coal research program and the large demonstration projects co-funded with industry under the third round of the Clean Coal Power Initiative.

West Virginia University is a public, land-grant, research-intensive university founded in 1867. It's designated an "R1" Doctoral University by the Carnegie Classification of Institutions of Higher Education. Funding for sponsored research programs and grants exceeded $185 million in 2017. In addition to the Energy Institute, the Morgantown campus also houses the Center for Alternative Fuels, Engines, and Emissions, which we call CAFEE, which discovered the Volkswagen diesel engine emission software issue that allowed its diesel engines in test mode to meet emissions compliance standards but to operate out of compliance when not in test mode.

Along with Ohio, Pennsylvania, Western New York and Southeastern Kentucky, West Virginia shares portions of huge natural gas and natural gas liquids in the Utica and Marcellus shale formations. West Virginia desires to harness the economic value of these reserves to grow the economy, attract industry, provide jobs, improve education opportunities and increase the wealth of its citizens.

Examples of West Virginia University's innovative research activities that support these aspirations include:

—Developing concentrated rare earth oxide extraction processes from U.S. coal mine wastes. This work is being done in collaboration with Virginia Tech and Rockwell Automation. WVU has constructed a lab scale operation producing commercial concentrations of rare earth oxides from mine sludge and acid mine drainage. Rare earths, as we know, are critically important to defense and industrial products and are largely produced in other countries that set prices and control availability.

—An area of promising research at WVU involves the replacing of high carbon-emitting steam methane reforming processes with catalyst thermochemical conversions of methane to CO_2-free hydrogen and solid, highly pure crystalline carbon. We are collaborating with Pacific Northwest and Southern California on that.

—Development of techniques and technologies to integrate state-of-the-art down-well innovative fiber optic and micro-seismic sensors; improvement in data collection, and production tools with advanced big data and machine-learning applications for accurate reservoir characterization and modeling of the Marcellus and Utica shales.

—In conjunction with National Energy Technology Laboratory, we are developing tools and techniques and above-well sensors that detect even small releases of greenhouse gases during the stimulation, drilling or production of operating shale wells.

—We developed complex combustion systems that burn fossil fuels in vessels containing inexpensive oxidants like iron oxide and aluminum oxide, models that can be used to develop technical solutions for combustion without air, which may generate pure, dense phase supercritical CO_2, ready to transport to safe storage locations or for reuse in enhanced oil recovery at wells that no longer have sufficient pressure to continue producing.

—Research into technical and economic advances of renewable geothermal sources of energy. It turns out Eastern West Virginia has valuable resources of geothermal energy, and WVU in conjunction with Lawrence Berkeley, Cornell and West Virginia National Guard are researching designs for the deep direct use of this resource on campus.

—WVU also led tri-state efforts with Ohio and Pennsylvania Geologic Societies and State Departments of Commerce to undertake rigorous sub-surface analyses of proposed Appalachian Storage Hub locations for natural gas liquids that will greatly reduce fugitive emissions for shale gas produced in Appalachia as compared to emission releases if that gas was transported to hubs south or east of Appalachia.

The Advanced Coal Technology Consortium managed at WVU is one of five consortia created through a bilateral protocol signed in 2009 between the United States Department of Energy and two agencies of the People's Republic of China. West Virginia's role in managing this consortium gives the university good visibility into China's research and development on solutions to carbon emissions and coal byproducts. Consortium members include University of Wyoming, the University of Kentucky, Washington University at St. Louis, several national labs and many private sector companies.

This research that is undertaken by the consortium includes advanced combustion technology including chemical looping and pressurized oxy-combustion and post-combustion carbon capture technologies and techniques including micro-algae absorption of CO_2 with co-production of medicinal chemicals.

West Virginia is committed to managing active, innovative and outcomes-based research that will improve the carbon footprint of the resources available in the Appalachian Basin so that industry and commerce may continue to grow and provide opportunities to its citizens.

Thank you for your attention.

[The prepared statement of Mr. Wood follows:]

James F. Wood

Interim Director, Energy Institute

West Virginia University

Written Testimony of James F. Wood to the U.S. Senate Committee on Energy and Natural Resources February 7, 2019

Chairwoman Murkowski, Ranking Member Manchin and members of the Committee, thank you for the opportunity to offer relevant testimony and to answer your questions in my areas of experience and expertise.

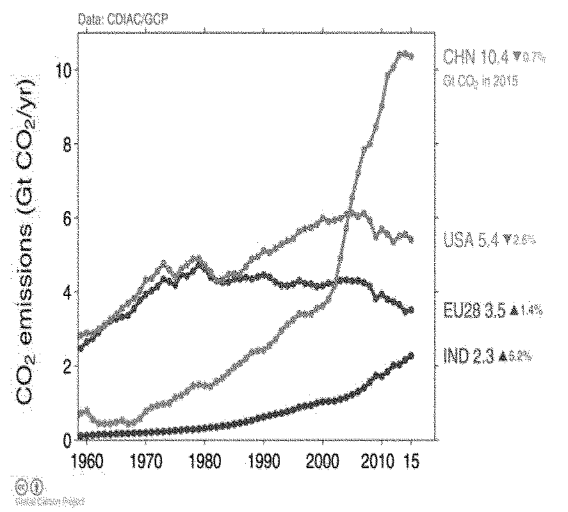
I am the Interim Director of the Energy Institute, the Director of the National Research Center for Coal and Energy (NRCCE), and the Director of the U.S.-China Clean Energy Research Center, Advanced Coal Technology Consortium, all based at West Virginia University in Morgantown, West Virginia. The Energy Institute serves to facilitate collaborative and innovative solutions for the energy future of West Virginia and the United States. The NRCCE conducts sponsored and grant-funded research programs. The Advanced Coal Technology Consortium is one of five consortia created through a bi-lateral Protocol signed in 2009 between the United States Department of Energy and two agencies of the People's Republic of China: the Ministry of Science and Technology and the National Energy Administration. Each consortium is funded 50%-50% by the Department of Energy with matching cost share from U.S. private sector enterprises including universities. The initial phase of Center's Protocol spanned five years (2011-2015) and in 2015 was extended an additional five years (2016-2020). From 2009 to 2012, I was the Deputy Assistant Secretary for what is now called the Office of Clean Coal and Carbon Management in the U.S. Department of Energy's Office of Fossil Energy. That position is responsible for the agency's coal research program and the large demonstration projects co-funded with industry under the third round of the Clean Coal Power Initiative, including funds added from the American Recovery and Reinvestment Act of 2009.

West Virginia University is a public, land-grant, research-intensive university founded in 1867. It is designated an "R1" Doctoral University (Very High Research Activity) by the Carnegie Classification of Institutions of Higher Education; funding for sponsored research programs and grants exceeded $185 million in 2017. In addition to the Energy Institute and NRCCE, the Morgantown campus houses the Center for Alternative Fuels, Engines and Emissions (CAFEE) which discovered the Volkswagen diesel engine emissions software installation that allowed its diesel engines, in test mode, to meet emissions compliance standards, but to operate out of compliance when not in test mode.

The university conducts innovative research related to operating improvements on existing coal-fired power generation, the recovery of rare earth elements from coal wastes, instrumentation and sensor development to accurately measure fugitive emissions from shale gas wells, produce analyses of sub-surface geological structures and their applicability to store natural gas liquids (NGLs), store carbon or produce natural gas. The university also has developed sophisticated software and algorithms that can model complex fossil fuel combustion systems, as well as complex electric transmission grids responding to variable generation from intermittent sources like solar and wind.

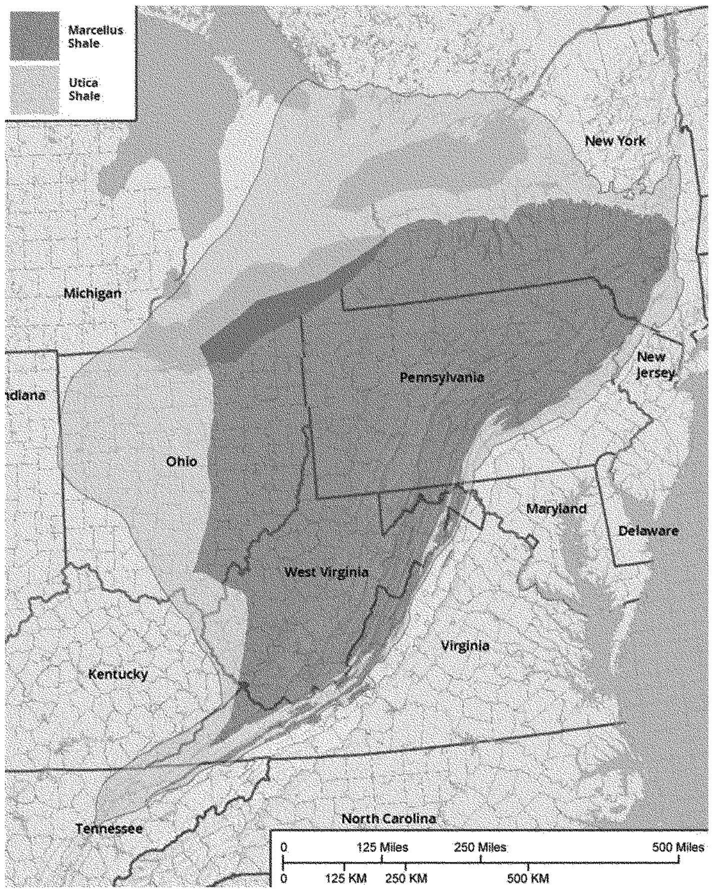
The United States has an abundance of diverse electric generation sources. Diverse sources of generation improve transmission grid operation, moderate retail electricity costs, and reduce unhealthy emissions levels. Benefits of this diversity are not unlike risk mitigation from diversity in savings and investment portfolios. Research into carbon emissions reduction is an important strategy to preserve the diversification of generation enjoyed by the United States. Carbon emissions have begun to decline in absolute numbers. This is due to substitution of lower carbon emitting and renewable generation for coal-based generation. Part of this is also is due to the reduced growth of energy demand over the last decade and one might expect this growth rate to increase as U.S. GDP growth rates increase. Having economic and commercial technologies to capture, reuse or permanently store carbon before its emissions are atmospheric, should be part of strategies to maintain the diversification of generation, and indeed provide economic benefits when these technologies are exported.

Many parts of the world are not equally blessed with diverse generation, and to a larger extent must rely on inexpensive local fuel sources high in carbon and resulting carbon emissions. Among these are the two most populous countries in the world, China and India. In the 2000 World Energy Outlook, the International Energy Agency estimated China's emissions would be 18% of the global total in 2020. In 2015 the actual value was 29%. Recently, Chinese President Xi Jinping announced China's carbon emissions would peak in 2030.



West Virginia has significant quantities of steam and metallurgical coal reserves. Along with Ohio, Pennsylvania, western New York and south eastern Kentucky, West Virginia shares portions of huge natural gas and natural gas liquids (NGLs) reserves in the Utica and Marcellus shale formations. West

Virginia desires to harness the economic value of these reserves to grow its economy, attract industry, provide jobs, improve education opportunities, and increase its citizens' wealth.



Examples of West Virginia University's innovative research activities that support these aspirations include:

1. Developing concentrated rare earth element oxide extraction processes from U.S. coal mine wastes, including acid mine drainage. This work is being done in collaboration with Virginia Tech and Rockwell Automation. WVU has constructed a lab scale operation producing commercial concentrations of rare earth oxides. Rare earths are critically important in defense and industrial products--- and are now produced in countries that often set prices and control availability;
2. Another area of promising research at WVU involves replacing high carbon emitting steam methane reforming processes with catalyst-based, non-oxidative thermochemical conversion of methane to CO_2-free hydrogen and solid, highly pure crystalline carbon nanotubes. Collaboration includes PNNL and Southern California Gas.
3. Development of techniques and technologies to integrate state of the art down-well innovative fiber optic and micro seismic sensors; improvement in data collection, and production tools with advanced big data and machine-learning applications for accurate reservoir characterization and modelling of the Marcellus and Utica shales These advances will better describe formation performance during formation stimulation and drilling, including gas production flow paths and flow paths of stimulation fluids and proppants that improve safety and well bore efficiency while simultaneously reducing the environmental footprint;
4. In conjunction with the National Energy Technology Lab (NETL), development of tools, techniques and above-well sensors that detect even small releases of greenhouse gasses during stimulation, drilling or production operations of shale gas wells. This work involves multiple researchers, including CAFEE, and has led to improvements in fuel efficiency of surface equipment and reductions of fugitive methane emissions further reducing the environmental footprint;
5. Models of complex combustion systems that burn fossil fuels in pure oxygen in order to explore the thermodynamic properties of flame development, which is a precursor to designing pilot and demonstration combustors with low cost carbon capture and efficient heat transfer properties;
6. Models of complex combustion systems that burn fossil fuels in vessels containing inexpensive oxidants, like iron oxide, or aluminum oxide, that can be used to develop technical solutions for combustion <u>without air</u>, which may generate pure dense phase supercritical CO_2, ready to transport to a safe storage repository, for reuse in enhanced oil recovery from wells that no longer have sufficient pressure to continue producing, and for new uses that are currently in research;
7. Research into technical and economic advances of renewable geothermal sources of energy. Eastern West Virginia has a valuable source of geothermal energy and WVU, in conjunction with LBNL, Cornell and the WV National Guard is researching designs for the deep direct use of this resource on campus and in Morgantown;
8. WVU also led a tri state (WV, PA, OH) effort with Ohio and Pennsylvania Geologic Societies and State Departments of Commerce to undertake rigorous sub-surface analyses of proposed Appalachian Storage Hub locations for NGLs that will greatly reduce fugitive emissions of shale gas produced in Appalachia as compared to emissions released if that gas was transported to hubs south or east of Appalachia.

9. Models of complex electric transmission systems that must maintain voltage, frequency and capacitance stability when multiple sources of diverse generation are competing to supply a demand curve that does not match the intermittent properties of the diverse sources of generation;

West Virginia University's role in managing the U.S.-China Clean Energy Research Center Advanced Coal Technology Consortium gives the university good visibility into China's research and development on solutions to carbon emissions and coal-to-products. Consortium members include the University of Wyoming, the University of Kentucky, Washington University (St. Louis), the National Energy Technology Laboratory, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Alstom (now GE) Power, Arch Coal, Duke Energy, the Electric Power Research Institute, the Gas Technologies Institute, Peabody Energy, the Southern Company, and Stock Equipment Company. Research undertaken by the consortium includes advanced combustion technologies, including chemical looping and pressurized oxy-combustion of coal, pre- and post-combustion carbon capture technologies and techniques, including micro-algae absorption of CO_2 with co-production of medicinal chemicals, and advances in carbon conversion technologies.

In the seven years subsequent to the Protocol signing ceremony, a number of important relationships have developed between U.S. and China consortium members. West Virginia University has ongoing collaborations with China Energy Investment Corporation Ltd., the world's largest power company and China's largest coal producer. There is evidence through these academic relationships that China depends on coal for approximately 85% of its energy needs. About 50% of its coal consumption is used in the generation of electricity. The balance is used to derive chemicals, and liquid fuels from coal. China's dependence on coal should not be underestimated, nor should effects of the lack of generation diversity on its transmission grid. As a consequence, China has made large commitments and investments into cleaner utilization of coal and particularly criteria and climate change emissions reductions. The chart below compares China's current regulations for criteria emissions with those of the U.S. and EU. The *, **, *** notations refer to location- relevant (usually Provincial) limits now overridden by the lower National Limits:

TABLE 1

Coal-fired power emission standards in China, the United States, and the European Union

Conventional air pollution standards for new and existing power plants, in milligrams per cubic meter (mg/m3)

		China	United States	European Union
Nitrogen oxide	Existing	100*	135	200
	New	50	95	150
Sulfur oxide	Existing	50/100/200**	185	200
	New	35	136	150
Particulate matter	Existing	20/30***	19	20
	New	10	12	10

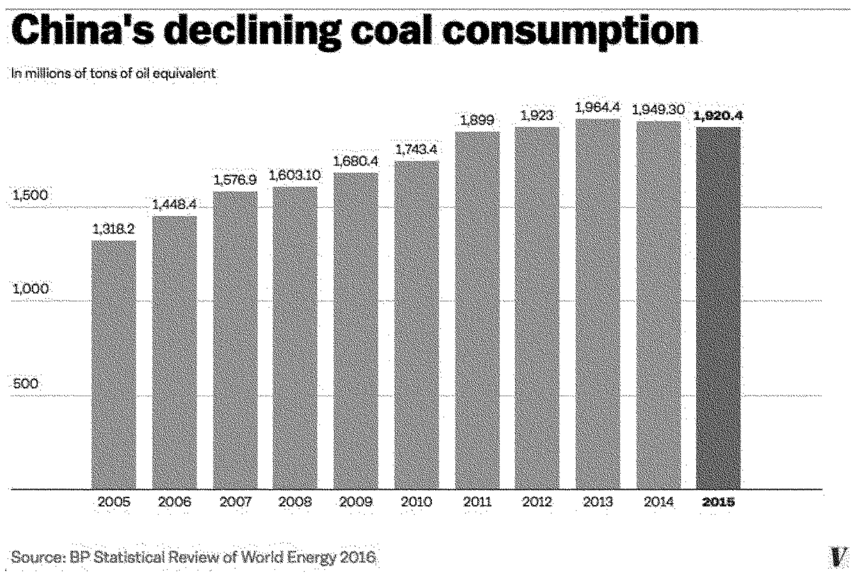
https://www.vox.com/energy-and-environment/2017/5/15/15634538/china-coal-cleaner

https://www.americanprogress.org/issues/green/reports/2017/05/15/432141/everything-think-know-coal-china-wrong/

China is an observant partner; it studies decisions other countries have made, and the consequences of those decisions. It appears that China's principal choice to reduce emissions from coal-fired electrical generation is efficiency increases to its coal-fired fleet. China's most efficient coal-fired plant is the 1000 MW Guodian Taizhou plant which operates at about 45% thermal efficiency (http://www.powermag.com/who-has-the-worlds-most-efficient-coal-power-plant-fleet/).

By comparison, the most efficient coal-fired plant in the U.S. is the privately-owned Longview Power LLC which operates at about 40% thermal efficiency. There is evidence that China's consumption of coal is declining. Some attribute this to an increase in renewable energy. While China is installing as much renewable energy as possible, it also has 36 nuclear power plants in operation, 21 under construction and plans to have 150 Gw, or approximately ten percent of its electric generation, in operation by 2030 (http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx).

China also is decommissioning its old, low efficiency coal fleet and replacing it with renewables and with high efficiency, low emissions power fueled with indigenous coal. For every megawatt of old coal capacity China replaces with new coal capacity, its criteria and carbon emissions decline 10% on a per unit of electricity generation basis, as does its coal consumption.



The low generation costs from renewable and natural gas-based electricity are putting pressure on the U.S. coal-fired base-load fleet principally because it operates, on average, at 32% thermal efficiency. Most of the operating capacity has been retrofit with criteria emissions controls and is well-maintained. However, because these units are called into service later in the daily dispatch cycle, they often operate below full load, and undergo frequent pressure and temperature cycles that were not accounted for in those plant designs. Operation at reduced load also reduces a plant's thermal efficiency, which increases its carbon footprint.

The U.S. Department of Energy's Office of Fossil Energy is leading an effort to develop design and manufacturing specifications required to develop a small-scale, modular, coal-based power plant of the future. Late last year, it launched the Coal FIRST (Flexible, Innovative, Resilient, Small and Transformative) initiative, which seeks to design smaller, more flexible coal plants. These plants are envisioned to be lower cost, able to load-follow the intermittency requirements of the evolving grid, and highly efficient (in excess of 40%). WVU's research on in-situ instrumentation and grid stability associated with intermittency will be important contributions to controls vendors who will need to imbed algorithms into control systems in order to safely manage load changes in these plants.

Since 2011, roughly 350 coal-fired generating units have shut down according to the Energy Information Agency (https://www.wsj.com/articles/coals-decline-spreads-far-beyond-appalachia-1497870003).

When an owner determines a plant is no longer viable it is mothballed and ceases to be maintained. The rotating equipment, electrical and controls systems decay rapidly. A similar issue faces the U.S. nuclear fleet which is not a carbon emitter. In both cases diversity of generation is reduced, investors or customers have expensive stranded assets to deal with, jobs are lost, and local property tax revenues decline, often with serious economic consequences to host communities.

There may be gigawatts of operating coal-fired generation that under some circumstances could be upgraded with technologies that would improve operating efficiency and reduce emissions, thereby allowing those units to compete for more operating hours and minimize the effects of cyclic operation. This month, the Department of Energy offered $38 million in funding for technologies that make the existing coal fleet more flexible and efficient. Some of these technologies could include conversion from coal to natural gas, replacing old turbine blades, condenser and feedwater heater upgrades, and control system upgrades. Increased interest from electric generators in efficiency improvements could benefit research centers and U.S. vendors that have largely exited this sector, or moved operations to Asia. To the extent these units then continue to operate economically, local host communities will continue to enjoy economic benefits associated with jobs and property taxes.

West Virginia University is committed to maintaining active, innovative, and outcomes-based research that will improve the carbon footprint of the resources available in the Appalachian Basin so that industry and commerce may continue to grow and provide opportunities to its citizens. The university also is committed to maintaining robust business and academic relationships with partners in Europe- and Asia. Trans-global collaborations like these accelerate the development of electric generation technologies that improve safety, improve maintenance and operating efficiencies, and promote adoption of technologies that control emissions and improve air quality. This helps regional economic expansion, promotes low cost electric generation from diverse sources, and improves transmission grid stability.

The CHAIRMAN. Thank you, Mr. Wood. Very interesting and sure to get us charged up for the New Year as we think about the goals and outlines for this Committee. But so many of us are talking about where we are going with technology, so the focus that you have provided here this morning is good.

I was looking, Under Secretary Dabbar, at the 75 Breakthroughs, and I think it is just a good reminder to us what comes out of our national labs. We all recognize the benefits that come from the supercomputing, but it is everything from working on photosynthesis to the protein data bank to powering NASA spacecraft to making refrigerators cool to discovering 122 elements, improving automated steel, the maglev train, the levitated train with magnets; early universe quark soup (I don't know what that one is), good and bad cholesterol. I mean it really is a reminder to us of the significance, and really so many of the day-to-day applications that then follow from the benefits of those national labs.

Secretary Moniz, again, I appreciated the conversation that we had yesterday about the Breakthrough Energy Report, and I look forward to absorbing that whole thing.

I am looking at your one-page handout here, as you talk about increasing and better targeting public investment. This is something that, as we look at the panel, is very key to it all.

But the statement that you have here is the government needs to better target investment in solutions that have the highest breakthrough potential and to do so at the most critical times in their path to commercialization. Absolutely positively agreed. Our problem around here from a policy perspective is we have this tendency to pick winners and losers. We decide who is going to be the favored child, if you will. And so when you are from the investment side of it, you want to be where you know that you are not going to be running up against the political or the policy friction so you go for those safer bets.

How do we do a better job of making sure that it truly is a more even playing field? I don't think that we should be the ones that are targeting the best investment solutions, because I am not sure that we know what it is. I think you all know more about that. Secretary Moniz, if you can address that—and anybody else who would like to speak to this—because I think it is a key part of how we move forward with these great technological opportunities. If you don't have the investment, it is hard to figure out how to make that go forward.

Dr. MONIZ. Thank you, Madam Chair.

First of all, let me reassert what Mr. Grumet said, that—and as you know, I've been a long-standing supporter of the so-called "all-of-the-above" approach. I think we really need to work on all of the low carbon pathways that we can see in front of us.

The CHAIRMAN. I like the fact that we are calling it carbon management.

Dr. MONIZ. Yeah. So the——

The CHAIRMAN. I think it is important.

Dr. MONIZ. I think another point is—and this goes back to the regional innovation also that we advocate—that there is no single low carbon one-size-fits-all solution. The resources, be they in terms of physical resources, the innovation resources, the nature of the industries in different regions are in fact quite different, and what we need to do is have the full quiver of arrows for which low carbon solutions can be fit to purpose in different regions of our country and in different countries.

Now, I would say at some level—I mean all the elements of the portfolio that we discussed at some level are, I would say, in the Department of Energy's portfolio, but we think that there is a significant reweighting that's needed. There is a significant need to focus on different time scales for moving to the low carbon economy, and, frankly, that is going to be very hard to do if we cannot increase the resource level that's available at the federal level, at the Department of Energy, at other departments as well. For example, I mentioned biological sequestration earlier. The Department of Agriculture has an enormous role to play.

And as I said earlier, that's easy to say and hard to do in the time of fiscal challenge, and that's why I think we need creativity on adding also new funding streams. We've done that not so long ago with some of the royalties from oil and gas production going into innovation. Years ago there was the FERC allowing, if you like, the surcharge, a small surcharge on interstate gas transmission to fund R&D, critical for what became the unconventional natural gas revolution.

So I think, again, this Committee can play a really important role in thinking about these creative approaches. We need that portfolio diversification. We need it to focus on these breakthrough opportunities, and that's going to require both design of the portfolio and, as I say, I think some significant additional resources.

The CHAIRMAN. We have a lot to talk about here. I am going to go to Mr. Grumet real quickly, and then I am going to step out. I have asked Senator Gardner to sit here with Senator Manchin as we go through the rest of the questions, and then I am coming back.

Mr. GRUMET. Alright.

The CHAIRMAN. So Mr. Grumet——

Mr. GRUMET. Well, thank you for letting me extend your time. I think what Secretary Moniz said is very important, which is we cannot pick technologies but we also aren't agnostic. Is the "all-of-the-above" toward a particular outcome? I believe low carbon has to be one of those outcomes. But that's what we need you all to do.

I think sometimes people just say "all-of-the-above," and that's like yeah, we just don't really—just throw money at everything. And I know that is not what this Committee believes and will raise but not answer what I think is the hardest question, which is the billion-dollar stair steps. You can invest a million dollars in a software app and provide a valuable service to the United States of America. And energy choices are billion-dollar choices, and that's hard and it's expensive, and we need to go all in on some things that aren't going to work, and that's really hard.

There's a culture of innovation. I've said if you're an investor and you're right 9 out of 10 times—I'm sorry. If you're an investor and you're right 1 out of 10 times, you're a billionaire; if you're a DOE official and you're right 9 out of 10 times, you're potentially indicted. So there has to be a different imagination of the risk profile that's going to be required to succeed.

The CHAIRMAN. I greatly appreciate that.

Senator MANCHIN. First of all, thank you, Madam Chairman, and I thank all of you for your wonderful testimonies.

There is a lot going on, and I know you have been hearing a little bit about the Green New Deal, and there is now, I think, a resolution coming out of the Senate on our side. If somebody wants to comment on that—and I think you all have in your testimonies to a certain extent, saying that this is in a perfect world an ideological belief. But in the real pragmatic world that we are living in right now, are we able to get there, what timeframe are we going to need to get there, how much are we going to have to invest, and is the rest of the world going to come along with us? Those are all the big "ifs."

Right now, I think there is about $40 million or $40 billion for loan programs at DOE?

Dr. MONIZ. There's approximately $40 billion left.

Senator MANCHIN. $40 billion. And there is about $11 billion that we have in research and development. Is that adequate to do the job? The $40 billion has been there for quite some time, I am understanding. We have not had a run on the loan programs.

Mr. Dabbar, you might want to speak on that, where we are and why there has not been more of a demand for that.

Mr. DABBAR. Yes, Senator. So approximately $11.7 billion a year is spent in non-defense R&D across the lab complex and, as you know, we are also a contract researcher. We actually get people who come in and hire us for another $2.2 billion a year. So that's the scope. It is a significant scope. It is larger than any corporation in terms of R&D.

Obviously, we have the loan guarantee program. The loan guarantee program in general is there to help support specific projects. In the big scheme of the capital markets, it's a lot of money, but it's not a lot of money in the scheme of the private markets. And so it is there really to support.

Senator MANCHIN. I am just asking why there has not been more of a demand for the $40 billion, because I think it has been there for quite some time——

Mr. DABBAR. Yeah.

Senator MANCHIN. ——and we have had a surplus. We have not had anyone either coming and asking for it or being a part of that loan program.

Mr. DABBAR. Yeah, Senator. In general, I think a lot of the times the way the program has been managed, it's about waiting for people to come to it. And at least one of the things that we've been trying to do—and I have some experience in this—is to actually be proactive and reach out. So some of the members of our loan program have actually been going to some of the trade conferences where the power developers who actually go out and build power plants for a living in the energy complex, to let them know that we're available, how to do it. Because a lot of times people don't know how, so we've been proactively reaching out.

Senator MANCHIN. Dr. Moniz.

Dr. MONIZ. Yes. Thank you, Senator Manchin.

First of all, the loan program, it has the order of $30 billion in play and I would say it's been extremely successful.

But Mr. Grumet mentioned that risk appetites are such that, you know, one investment defaults and the whole portfolio is talked about, and yet it's been extremely successful as a portfolio.

Now, going forward, I agree with Secretary Dabbar that reaching out is important. For example, there were investments made successfully in auto battery manufacturing. But reaching out to the supply chain now is an example of something that can be done. Using the program for advanced nuclear could be something very important in the next years.

But I'd like to emphasize a third area, and I think the Committee might help in clarifying the availability of the remaining authorities for energy infrastructure. The Administration and, I believe, the Congress are very much supporting energy infrastructure. Well, here we have $40 billion of authority which, when matched with private sector equity investing, for example, we could have $80 or $100 billion of energy infrastructure investments. Let's get on it. And that doesn't require an appropriation.

Senator MANCHIN. Dr. Moniz, thank you.

Real quick, and I have one final question for Mr. Grumet, but—

Mr. Wood, as far as the work you all have been doing on extracting rare earth minerals that we need so desperately in our country—because right now we are depending on China as I understand—how is that coming along, and when do you think that we could be commercialized to the point that we could have our own supply, if it is possible, Jim?

Mr. WOOD. It's coming along a lot faster than I would have thought six months ago. We have built a laboratory in the high bay at WVU. We have staffed that with some people. We have run in some acid mine drainage and some sludge, and we have produced better results than we told the Department of Energy we would produce when we got the cooperation agreement signed.

We're now taking a trailer and taking it out on the road to acid mine——

Senator MANCHIN. Okay.

Mr. WOOD. ——locations and producing oxides of rare earth. The quality and the concentration of rare earths that we are getting of the process that we have designed and the intellectual property that we have, which we haven't protected yet, is very good, better than we thought it was going to be, so I'm very optimistic that——

Senator MANCHIN. Right.

Mr. WOOD. ——this process as relates to mine wastage is going to be commercial in a year.

Senator MANCHIN. Wonderful.

Mr. Grumet, just a final question very quickly. Being the bipartisan committee that you are and the group of people you put together in your organization, how can you best help us as a Congress and the Senate? We have a lot of our colleagues focused on the Green New Deal. And it is very—you know, we are excited about people having all different ideas of how we get to where we can save our planet and decarbonize, but also in a practical way.

What is your best way of making sure that we are all working off the same set of facts? Because right now, I think there are some people moving in their opinions and trying to create their own facts to justify their opinions versus working off a set of facts from which we can all find a solution.

Mr. GRUMET. Senator, I think the optimistic take right now is there is now symmetry of magical thinking about the climate change debate on the left and on the right.

Senator MANCHIN. Good.

Mr. GRUMET. And the only way that's going to change—and I think this is something I think you are uniquely good at—is if members enforce against their own edges. It does nothing to have the Sierra Club and the Heartland Institute yelling at each other.

I think most members of the Republican party believe that climate change is real but tend to avert their eyes when people say it's not, because like why pick up the fight? And I think most all members of the Democratic party know we are not going to eliminate fossil fuels in 10 years or go to 100 percent renewables but they kind of avert their eyes, right, because like that's where the energy in the party is and, you know, no one wants to be on the wrong. Then we just seed it to the edges. Alright?

I think this Committee fundamentally knows that both those things are wrong and that the answer requires an evidence-based approach to both. It's not popular to say it, but the only way we're going to make progress is if you do.

Senator MANCHIN. Thank you.

Senator GARDNER [presiding]. Thank you, Senator Manchin.

Senator Hyde-Smith.

Senator HYDE-SMITH. I want to thank the panel today for your expertise. You're sure going to be helpful when we are deciding on legislation to vote on.

Mr. Faison, you know as we well know our revolving needs will require innovation and significant investment in the energy sector. And in his written statement, Under Secretary Dabbar had discussed the essential need for the basic research. In your opinion, how much involvement should DOE have in research and new technologies?

Mr. FAISON. I think just coming at this from an outsider's point of view, somebody who does not have all the insights, obviously that are here on the panel, I have always been confused by the distinction between basic research and applied research.

I don't think the Chinese have the same distinction. I think they are focused on outcomes. I've heard one guy say one time that scientists look for outcomes and business people look for—scientists look for learning and business people look for outcomes. And I think that we need to look for outcomes and then plug the holes that we have in that technology-development ranking system so that we can compete with the Chinese.

I'll give you one example: A123 batteries. We do a great job at the basic research. Companies spin out and then they go to market. There's no incentives for their products, there's no financial support; they're kind of out on their own. They declare bankruptcy, and the Chinese buy them for cheap and scale them up. That's been a pretty consistent happening, and I think that's something we need to fix.

Mr. GRUMET. Senator, if I could just add one insight on the scale of the challenge, and again it comes back to the unique characteristics of this industry that the Secretary talked about.

The energy industry does a ton, but it devotes—0.3 percent is total capital to R&D; pharmaceuticals, about 20 percent; electronics, about 10 percent—and this is because they are making rational choices. The industry does not have the capacity to recoup the benefits of those early investments. They are expensive; they take a long time.

And so when I think we think about imagining our innovation across the entire portfolio of what the government cares about, I think energy is going to have to play a bigger role. The government and the private sector are going to have to work together and understand that the energy industry is no different than the pharmaceutical industry if we're going to make this progress.

Dr. MONIZ. Mr. Chairman, may I just have a comment, because it goes directly to the Senator's question and Mr. Faison's statement about the basic and applied?

Frankly, the whole innovation chain is much more integrated with all kinds of feedbacks than is generally acknowledged. It's not some linear thing that happens. And a consequence of that is one reason in our report why we emphasize that the Federal Government and the Department of Energy are one very important player. There are others. But that player, in particular, really needs to work across the innovation chain, not fall into the trap of this false linear separation. And in doing so, that will address part of the issue that Mr. Faison announced, that we cannot leave the "playing field" beyond the basic research to a place like China. We need to compete along that entire feedback, feedback system.

Mr. DABBAR. Maybe I should comment since it was a bit about us across the board here.

You know, I think, Senator, this goes into the balance between curiosity and usefulness, and the way we like to think about it in terms of a portfolio of the different investments that we're doing. We certainly pursue a lot of fundamental understanding of physical phenomena such as quark and gluons and how they hold together, neutrons, and not knowing exactly where they go in terms of that research, and then the balance of looking at things that have practical and useful applications.

I'll give you an example. Our computing power—this is a non-energy example but something a lot of people may not know. If you look at the computing power and the imaging, a lot of which was used for atomic level structure, that some people basically at one of the weapons labs at Livermore were poking around about and figured out that they could use the same computing power and the same imaging to sequence genes. And most people don't realize the Human Genome Project was predated by something called the Human Genome Initiative which was started at Lawrence Livermore National Labs, and they brought that to the National Institutes of Health and it spread from there. So it's a non-energy example.

But one interesting thing about the national lab complex, and people don't really understand if you don't spend a lot of time here—a lot of people do spend a lot of time there—it's actually quite entrepreneurial. We allocate the capital, the budget that you give us and we send it down to the principal investigators and we give them the flexibility within bounds of certain areas that you guide and we guide them on and then we kind of let them go. And a tremendous amount of this innovation that people are talking about here today is based on the entrepreneurial spirit and the flexibility that we give them. And as the Senator, as the Chairman announced, there's a long list of these examples, far too long to get into.

Senator GARDNER. Thank you, Senator Hyde-Smith.

Senator Stabenow.

Senator STABENOW. Thank you, Mr. Chairman. This is a very important discussion. Thank you to all of you. In fact, I can't think of a more important discussion, and there are a lot of things that I care about.

Mr. Grumet, first of all, I could not agree with you more about a national goal and understanding of where we are going and the sense of urgency that we need to have to get there and that we need—it is not ideological. We need to be looking at the practical fact of how we cut carbon pollution so that we are addressing the threats to, frankly, our way of life, and taxpayer costs. We are seeing it every day in extreme weather, health risks, and everything else. It is clear what is happening. So I hope we can do that, and I think this Committee could come together to do that.

And also, Ms. Wince-Smith, I appreciate your focus. Everyone talked about investments, but thank you for talking about best investments and advanced manufacturing, which we know a lot about in Michigan. I could not agree more with you about the focus on workforce development. I think that, from an economic standpoint, certainly in my state, it is the major barrier right now to moving forward in terms of where we need to go on the jobs front. So I appreciate that very much.

I do want to comment on how Michigan has benefited from a great industrial revolution, where 100 years ago we embedded incentives in the tax code on oil, gas, and coal. We benefited from that. We also understand now that we are paying the price of carbon pollution, and we better figure out a different way to do this where we can still prosper economically, which is what we are now doing.

And so Joe, when we talk about jobs, there are 8,000 parts in a big wind turbine and we are prepared to make every single one of those in Michigan. But you can do some in West Virginia too.

There are jobs, and I just want to make a point about how we say we should not pick winners and losers. A hundred years ago, we picked winners. They are embedded in the tax code. Even in the new tax laws, there is a new $4 billion tax benefit for oil and gas. So it is amazing that wind and solar are doing as well as they are. They are incredibly competitive. And I am all for not picking winners and losers if we are really unleashing the private sector.

I have to, coming from Michigan, talk about the transportation sector and ask a question. We know at this point the transportation sector generates the largest share of greenhouse gas emissions and, according to EPA, 90 percent of the fuel is still petroleum-based. We have to be very serious about what we are doing.

There are great new technologies. I appreciate very much that our auto manufacturers are investing aggressively in new advanced technologies over the next five to ten years. This is very important. But they cannot do this, just as in any other country, by themselves without a public-private partnership. And at the moment, we have 1.3 percent of the U.S. light-duty fleet in electric vehicles or hybrids, and yet we have to get that to about 10 percent to be sustainable here in terms of the economics of it, and that relates to charging stations, tax credits to continue, and so on.

So one other thing before a question, and that is China. While they are doing everything—they are doing all-of-the-above, right? Everything. But one of the things they are doing—this last year they spent $7.7 billion on electric vehicle subsidies alone, and they are not debating whether or not they are going to put in infrastructure. I mean no other country is debating that at this point. And now they are going to hydrogen-powered vehicles.

So when we look at this, and I will start with Dr. Moniz, what policies should we be pursuing to pursue the investment in the widespread adoption of advanced vehicles, and are these investments critical to ensuring that we remain a leader and can be successful in this area?

I have asked Dr. Moniz; and then, Ms. Wince-Smith, if you would like to chime in and anyone else.

Dr. MONIZ. Thank you, Senator Stabenow. The transportation sector is indeed one that we really need to focus in on because of its—it's the data.

Senator STABENOW. Right, right.

Dr. MONIZ. It is the biggest emitting sector and it is not the easiest sector to decarbonize.

It may be worth putting something in perspective in the sense that if we look at say California, which has always played a major role in advancing the transportation issues that the goal of California is five million zero-emission battery vehicles basically in 2030. But we should have the context. That's out of 35 million light-duty vehicles, not even counting heavy-duty vehicles. So all of these themes come together just in those facts.

Now, to make these transformations occur, infrastructure is a huge issue. So obviously for electric vehicles the charging infrastructure is a major challenge. That is relatively easy compared to some other infrastructure challenges. If we went to hydrogen, for example, much more expensive, much more difficult; and yet it's chicken-and-egg. We're not going to get there without the infrastructure being built, and that may be especially important for things like heavier vehicles than the light-duty vehicles, so that's a big challenge.

But then again, in the innovation arena, we could have breakthroughs that really minimize some of those challenges in the sense of, okay, suppose we do develop an affordable, low carbon substitutable fuel, a hydrocarbon, basically, fuel but with different feed stock. Well, suddenly the infrastructure isn't the issue; it's the innovation of the fuel itself. And that goes into this, I think, theme: that we need—it's a relatively inexpensive investment given to work across the board on those issues in terms of the prize that would be at the far end.

So I think all of that's important. And that's where again going back to the earlier statement—it's not the only example; I don't want to beat a dead horse—but something like the loan program might be an important way of providing debt financing for getting some of this infrastructure built.

Senator GARDNER. Thank you, Mr. Secretary.

Senator Barrasso.

Senator BARRASSO. Thank you, Mr. Chairman. Mr. Chairman, since my earliest days in Congress I have been diligent about developing legislation and policies to advance carbon capture technology that many of you are aware of. My home State of Wyoming is a national leader in oil and gas and coal production. I am very supportive of all of these industries as they keep our world running, and they provide critical jobs and revenue for Wyoming.

In my view, it is necessary that we continue to develop traditional energy sources while simultaneously pursuing advancements in carbon capture technologies. We do not have to choose between these two goals, and, in fact, I have a record of developing these policies in a bipartisan and bicameral manner. So I want to emphasize the importance of developing successful technologies and practices here in the United States. When these technologies are successful at home, we can then export these discoveries around the world.

So today, along with my friends and colleagues, Senator Whitehouse from Rhode Island and Senators Capito, Duckworth, Kramer, Smith and Manchin—thank you, Joe—and then Senator Carper as well, we are introducing again the USE IT Act. This bill supports carbon utilization and direct air capture research, and it encourages the commercial use of man-made carbon dioxide emissions. The USE IT Act encourages the development of carbon capture, utilization, and sequestration facilities and carbon dioxide pipelines. In our last Congress, this bill had broad bipartisan support, and I look forward to passing the USE IT Act into law this Congress.

My state is also the home to the Integrated Test Center, the ITC it is called, in Gillette, Wyoming. This unique facility allows for research and testing at an active power plant, allowing for real world discovery. I am proud of what is going on in Gillette, and it is becoming the world's Carbon Valley. I will continue to work and lead the policy discussions here in Washington to advance these groundbreaking solutions.

In addition to using Wyoming's vast oil, gas and coal resources, uranium mined in my home state can provide clean, affordable electricity through the development and deployment of advanced nuclear technologies which have been mentioned today. Last Congress, the bill that I introduced, the Nuclear Energy Innovation and Modernization Act, was signed into law with the purpose of doing just that. So I am looking forward to the innovations that America's nuclear scientists and engineers will create as a result of this legislation.

Secretary Moniz, earlier this week you discussed a recent report issued by your nonprofit, the Energy Futures Initiative. You said that a 100 percent renewable system by 2050 is not politically or economically realistic. I visited with Bill Gates last weekend about the same issues. You also mentioned the importance of natural gas in balancing the energy mix into the future. This is an abundant, affordable fuel source, that yields less carbon emissions as compared to other fuels.

Can you talk about how you view the use of traditional fuel sources in the short-term and then in the long-term, realizing this gap continues to exist?

Dr. MONIZ. Thank you, Senator Barrasso.

I believe that statement on the all renewables was in the 2030 timeframe.

Senator BARRASSO. I am sorry, yes.

Dr. MONIZ. However, also in the longer-term, I do think, as I said earlier, that there are going to be different kinds of low carbon solutions elsewhere. And, for example, I strongly agree with your position on the importance of developing what we call the large-scale carbon management options like carbon capture utilization, sequestration—not only geological sequestration but biological sequestration—capture from both concentrated and dilute sources like direct air capture, for example; utilization in major commodities.

So this is a critical need. I believe, and the IEA has stated, that we are going to need those tools, the CCUS tools, if we are going to, in a reasonably economic fashion, be able to meet the very, very low carbon goal.

I'll just add that I think we need a lot more work on novel carbon capture technologies because that's actually the big cost center in the entire—in the entire chain. We need a lot more basic science in CO_2 utilization at gigaton scale. And on sequestration, we do need more science done. But we also need to think about—and this is something which of course has come up in the nuclear context a lot as well—we need to think about public attitudes. The ability to—to sequester gigaton carbon dioxide annually, for example, is a big challenge I think in the—it will be a big challenge in the public view about that much underground storage.

Senator BARRASSO. I only have a few seconds left, and I am going to go to Mr. Faison. I have a question for him.

Reducing greenhouse gas emissions is a global challenge. The U.S. is capable of developing the technologies to address climate change. As other countries grow their economies, they should be using the best possible technology to capture emissions. As the Asian countries continue to grow, how quickly can we quickly develop and deploy the emission control technologies that we are going to be leading on?

Senator GARDNER. Would you press your microphone, please?

Mr. FAISON. Thank you for the question, Senator Barrasso. And also thank you for your thoughtful op ed in the New York Times and your sponsorship of the Nuclear Innovation—Energy Modernization and Innovation Act. Really important.

As far as scaling up quickly, I've been to the centers out there in Wyoming and we are huge proponents of that. I think if you look at the National Carbon Capture Center, the other major public-private partnership in Wilsonville, Alabama, we are, I think, severely underfunded in those areas. And so one I think it's not invested in at the scale and level that it should be given that Asia's coal is really sort of, at least in the energy sector, you know, a majority of the global greenhouse gas emissions growth that we have worldwide.

So interestingly, you're seeing these cross-cultural opportunities. For example, I met the India Prime Minister of Coal in Wilsonville, Alabama, and he brought a whole team over to learn from us. They want to catch up. Their oil wells are depleted. They could use this to domesticate their oil supply and grow their coal technology, and they're going to do it regardless of the impact. And so there are some green shoots, and I think we just need to build on that—more money and more attention and focused goals.

Senator BARRASSO. Mr. Chairman, my time has expired. I know the Secretary has had his hand up, so——

Senator GARDNER. Mr. Secretary, briefly.

Mr. DABBAR. Yes. Thank you, Senator.

I want to point out one particular area at NETL in West Virginia and in Pennsylvania that we have going on that I am particularly excited about. Obviously a lot of carbon capture just deals with basically how do you screen out the molecules. And one of the things that we've done is using the computing power that you all have given us is to be able to go through a whole series of materials to identify what sort can screen out the molecules of carbon dioxide basically in a film. And we can go through millions of different types of designs of materials and be able to narrow it down, so before we get to the lab, we have a pretty good idea if it is going to work, and we are using artificial intelligence to help drive that.

We have a series of material in which there is a possibility—and I do not want to go too far because this is research—that the sort of film that we have developed that could just literally screen out the molecules could be in the range of $40.00 a ton. And when you ask the researchers how far could you push that, they think they can push it even farther in terms of lowering the costs of screening out. So when you stop and you think about the practical realities of the research that we are doing, that we are doing at the labs that you all fund and we start getting down to realistic numbers, when people start talking about things and other policies—and once again, I think, as we've talked about, I think technology can be the solution—that's a very particular one that I want to make certain people kind of hear about which way we're going, and I'd like to thank you for the support of that.

Senator GARDNER. Thanks, Mr. Secretary.

Senator Heinrich.

Senator HEINRICH. I am going to continue along with that with Under Secretary Dabbar.

I want to ask you, when it comes to platforms, have you or the Department of Energy looked at AI and machine learning as a way to more effectively manage the grid and do it from a point of view of responsiveness and lower carbon intensity?

Mr. DABBAR. Yes, Senator. So we have several programs using AI and machine learning for grid and energy management. I'll give you three examples.

First of all, the smallest one which is building management. So there's probably no one running this building right now in terms of when to turn on and off the lights, when to turn on and off the air conditioner, so it's highly inefficient in the big scheme of things.

It takes a pretty simple artificial intelligence set of data to develop an algorithm to run this building based on data of when people come and go and so on. We have a series of research at Berkeley, at Lawrence Berkeley, on that.

Number two, in Washington State at Pacific Northwest Labs—it's a leader in grid management—we work with the Bonneville Power Authority. It's a test-bed utility that we own. And we have built a series of machine learning algorithms to collect all the data of all the municipalities, all the interconnects down to California, all the wind, all the weather, day after day of data. And for example, for our dams that we have, what the buildup of the water is. And it is giving us now—we are working with that and Bonneville to predict any problems and to give us direction on how to dispatch our dams.

As we all know, grid management has historically been three people sitting in a——

Senator HEINRICH. Right.

Mr. DABBAR. ——control room dialing and using their judgment.

Senator HEINRICH. Yep.

Mr. DABBAR. This should be a machine learning algorithm. Maybe I won't go drop so far as artificial intelligence and handing——

Senator HEINRICH. Right.

Mr. DABBAR. ——it over completely, but clearly we are, and it should be, all the grid should be machine learning.

Senator HEINRICH. Great.

Direct air capture. Maybe I will start with you, Dr. Moniz, and then go to other folks if they want to add to that. What is the state of technology, what is the role of policy in moving that forward, and what are the best policy tools to get that to a place where it is actually going to be more economically attainable? Because we are sitting at 411 ppm right now.

Dr. MONIZ. Say that again?

Senator HEINRICH. We are sitting at 411 ppm and——

Dr. MONIZ. Oh.

Senator HEINRICH. ——there is more every year. We are way past our carbon budget. So if we are going to do something about this, we are going to have to get direct air capture up and running.

Dr. MONIZ. I would add, Senator Heinrich, that we are at 411 or so in terms of CO_2 but we should also remember that the other——

Senator HEINRICH. All of our short-term——

Dr. MONIZ. ——greenhouse gases, which really——

Senator HEINRICH. Methane——

Dr. MONIZ. ——with the very imperfect equivalence, which is above 450 already.

Senator HEINRICH. Yes.

Dr. MONIZ. So that's one reason why I agree with what I think you said implicitly, that we are going to need these direct carbon removal technologies.

I do want to emphasize that removal from the atmosphere also can be done biologically——

Senator HEINRICH. Okay.

Dr. MONIZ. ——and well beyond simply planting trees, and so that's also an important part of the research.

In terms of the current technology for air removal, I think the first thing to say about the status of the technology is it's very expensive. There are debates about that, but I certainly believe today, quite honestly, one is $500 and north, frankly, per ton. So we have a long way to go in terms of some undiscovered approach.

I think what Paul Dabbar just mentioned in terms of the kind of materials by design, for example, could be a contributor to resolving that, but we have no answer. We have some who would say that they have line-of-sight to the order of $100 a ton. I am not quite there yet, but—they have better eyes, apparently, than I do—but if one could reach that, that would be a transformative development.

Senator HEINRICH. I am quickly running out of time, but I want to go to Mr. Grumet. In addition to what you want to add on direct air capture, talk to me a little bit about how we build risk tolerance. You look at the solar panels, I mean in 1970, it probably would have cost you, I don't know, $150,000 to put enough solar panels on your house to run your home. Every time we doubled manufacturing capacity that went down 20 percent. Today it is at incredible levels. But if you listen, if you were around here when the word Solyndra was popular, you would think that we were making no progress on that. So how do we build that risk tolerance? Because we are going to fail, and we need to fail in order to succeed.

Mr. GRUMET. Well, first of all, Senator, thank you for bringing an engineering degree to this conversation. I think that makes you quite an unusual member of the Congress.

First, just on direct air capture, obviously I think the Secretary laid out the big picture. But in terms of what, you know, the Congress and this Committee could do, the National Academy of Science has laid out a really thoughtful agenda for the next decade, and our opinion is that to achieve that in the next year, we need about $60 million, so just to give you kind of a scale. Potentially, direct air capture could fundamentally change this entire equation, and so I think it is a very high upside and high-risk opportunity.

And that goes to your other question. I think there really has to be a conversation about what innovation means. You know, when the Congress passes a loan guarantee, you score it usually at about 10 percent, which means you are assuming that $1 out of every $10 will not be successful such that the company will not be able to pay you back and the taxpayer has to. We have done much better than 10 percent. But still there is this reluctance to tolerate that failure.

And again—I don't want to bring it back all the time—I think it just comes back to the climate debate. There were a lot of people who were very frustrated with what they believed to be the Obama Administration's approach on climate change, and anytime anything screwed up there was a "gotcha" moment.

And you know, this Committee should never tolerate mismanagement. You absolutely have to put DOE on a path to success with gateways and oversight, but things are going to go wrong and the other team is going to be in charge, and what the Committee does at that moment says a lot about whether we send the kind of consistent signal that's going to be necessary for success.

Senator GARDNER. Thank you, Senator Heinrich. I have a couple of questions for the panel, myself. Thank you to all of you for being here and for your distinguished service. But one particular thank you to Secretary Moniz for being here. Seventeen inches of snow for Telluride over the last 72 hours, so just so you know, we are heading out there next.

Dr. MONIZ. I like snowpack out in Colorado.

Senator GARDNER. Very good.

Secretary Dabbar, thank you very much for your leadership. The National Renewable Energy Laboratory in Colorado is an incredible, incredible crown jewel of our energy ecosystem and the work that they do out there. We had the opportunity to travel there with Secretary Perry in the last several months and look at a number of projects they have.

I would like to follow up with you a little bit more about how we make sure that they are coordinating with other areas of the Federal Government because I think Secretary Moniz's testimony makes a good comment about how the renewable energy work that may be taking place in other parts of the government, like within USDA, how are we coordinating across the agencies with the Department of Energy like NREL to make sure we are not "siloing" off, I believe is the term Secretary Moniz uses, when it comes to clean energy efforts.

Secretary Moniz, we talked about all-of-the-above strategy. In your testimony you say this: that a large American company that makes up the American Energy Innovation Council argued for tripling federal clean energy investment, but more than increased funding is needed. In your testimony you state the federal energy innovation portfolio, it is our innovation chain, actually, needs to be all-of-the-above. What do you mean by that? How do you go to all-of-the-above energy, all-of-the-above sort of innovation?

No, go ahead, Secretary. We are going to follow up. That was the warning that I am calling him later.

Secretary Moniz.

Dr. MONIZ. Thank you, Senator Gardner.

So yeah. So first of all, we do support the AEIC notion. And by the way, that can be very loosely argued to in terms of the generally-accepted level of federal R&D funding broadly combined with the fraction of the economy in energy, and it kind of gives a loose support to the AEIC objective. But we do need to go beyond that. And I would add, however, going beyond that is certainly made easier if we can get the additional resources to our friends at DOE and elsewhere.

So there the—what I mean by "all the above" is that every way of getting to low carbon technologies that can contribute to the future needs to be in our robust portfolio.

What I said earlier, and it's also in the testimony, that reinforces that is I think history shows in this country that betting on prescribed outcomes, prescribed answers to a problem is far inferior to betting on the outcomes of innovation and having our—having our scientists, our engineers, our policymakers, our government officials——

Senator GARDNER. If I——

Dr. MONIZ. ——in that framework.

Senator GARDNER. Yes. If I could interrupt right there because I think it is a really good question. Do we like the energy because of the technology or do we like the technology because of the energy is the question. I mean, do we like gas because of the energy or do we like, you know, the energy that comes from big gas? Is that what we like? So I think that is the question that we have to answer here, gasoline or fossil fuels or renewable energy, those kind of things.

Dr. MONIZ. And time scales come in. Obviously, in ten years, it's with technologies that we now see improved somewhat; but longer-term, let's let the innovation get turned loose.

Senator GARDNER. In Colorado, Xcel Energy has been doing some pretty incredible things. They have set up some very aggressive goals when it comes to emission-free energy. They are doing a remarkable job. They are about 23 percent carbon-free production right now, generation. But 60 percent of that carbon-free energy is—of that 23 percent, 60 percent of that production comes from nuclear.

So in any scenario, whether we are looking at existing technology, do you see a path to emissions-free energy in the next 10 to 20 years that does not involve nuclear energy? And this is a question for everybody on the panel.

Mr. DABBAR. If I have the risk of saying something—not saying something nice about the other 49 states, I actually think Colorado is actually the most interesting piece of data that's about to come out this year. You mentioned about Xcel.

But one particular area that's going on right now is that they did exactly what Secretary Moniz was talking about in terms of what the target—not technology but what you're trying to accomplish. And when they put out offers—and there's public information but they haven't selected winners, but if you see the firm renewable bids; so this is batteries and solar or wind and solar bids that came in, they published the average prices, and so you kind of know where things are going to end up. And so there were firm renewables—batteries and/or batteries and solar—at around $31.00 a megawatt-hour. They didn't publish the gas prices bids. They blanked it out. I just happen to know a little bit about power trading. The dollars about that for a 20-year bid are about 45 in Colorado. So the odds of this year firm renewables, batteries plus renewable, clearing in Colorado seems highly likely. I'll leave it at that. They're kind of moving down that road of analysis.

What's interesting is if you back out the tax policy, the IDC and the PTC, they're pari passu. So going to—this was a much larger discussion around batteries and nuclear and solar. But on the narrow point of technology, without any incentives, it looks like the price for power for firm, whether it's gas or it's renewables, in Colorado looked like it's about the same. I think this is a really important piece of data.

Senator GARDNER. Thank you for bringing that up. Thank you. Could we go back to——

Mr. GRUMET. Just if I could——

Senator GARDNER. ——the question.

Mr. GRUMET. ——answer your question?

Senator GARDNER. Yes.

Mr. GRUMET. Nuclear power provides about two-thirds of our existing non-carbon energy. The idea that we would start swimming farther away from the shore just makes no sense to me. And if we believe that climate change is a kind of, you know, global species-challenging problem, we should be doing everything we can to sustain every single non-carbon electron we have and, you know, we're going to need new nuclear technology. But trying to—you know, absent existing technologies from that discussion, I think would be a terrible mistake.

Senator GARDNER. I am over time, Mr. Faison.

Mr. FAISON. I think if you look at the examples of France and Sweden versus Germany, France and Sweden deployed clean energy at five times the rate at Germany, and France's electricity bills are 45 percent less than Germany's. And so if we have new nuclear technologies that could be built and manufacturing plants, my guess is we could scale multiples faster than we could on renewable deployment.

Senator GARDNER. Thank you.

And with the leniency of my colleagues, Secretary Moniz.

Dr. MONIZ. This will be extremely brief, but just to follow up on Paul's point, yes, so-called firm renewables have made tremendous progress and it's great, but we can't only talk about two- to four-hour storage times. We have a lot of other issues in evolving the system.

Senator GARDNER. Thank you.

Ms. WINCE-SMITH. I have to jump in on the workforce issue on the nuclear——

Senator GARDNER. Briefly, briefly please.

Ms. WINCE-SMITH. Right now we have a very weak workforce in nuclear, and young people are not going into nuclear engineering except perhaps at the Naval Academy and MIT and RPI. And if we want the next generation of talent in the nuclear industry, that's something we really need to focus on.

Senator GARDNER. Very good point. Thank you.

Senator King.

Senator KING. Thank you. A couple of preliminary observations.

Dr. Dabbar, please apply artificial intelligence to the scheduling of Senate hearings. We are all supposed to be at two or three places at once, and none of us have managed to do it.

I just want to follow up on the comment of Senator Heinrich. He mentioned we are now at about 400-plus parts per million of carbon in the atmosphere. The last time we were there was 3.6 million years ago, and the average temperature in the Arctic was 60 degrees, so that just gives you a flavor of where we are. We are in totally uncharted territory now, and I do think it is urgent.

Secretary Moniz, it is wonderful to see you. As a fellow New Englander, I am sure you are glad, as I am, that the Patriots ended the terrible three-month drought in world championships that we have had——

Dr. MONIZ. I was there.

Senator KING. ——since the Red Sox won in November, so it has been tough but we made it through.

Dr. MONIZ. The Celtics are coming on.

Senator KING. Senator Cantwell, you are recognized.

[Laughter.]

Senator KING. I just could not resist.

"Moonshot" has been used a number of times, and I think it is fascinating that the origin of that term is the Apollo program, and the key to it was Kennedy saying we are going to it in ten years. The other example of the government is, I think it was, Lyndon Johnson said we are going to get a train from Washington to New York in three hours. A concrete goal is what made those two things happen.

How do we—what should be our concrete goal in energy? I don't think ten years is realistic, but shouldn't there be some number? Because otherwise we don't have anything to shoot for. If you are going to do a moonshot, you have to know what it is and where you want to land.

Mr. GRUMET. So I'm going to give you a few suggestions and then I'm going to turn it over to Jay, who's also talked about this a lot.

You know, there is an intellectual sequence to get there. The first thing we have to do is decide what the problem is.

Senator KING. Exactly.

Mr. GRUMET. Once we decide what the problem is, then we have to have a general and philosophical sense of how we want to approach it, and I think most people on this panel would say a performance standard: a zero-carbon or a low-carbon as opposed to a particular technology. And then you have to do something a little harder, which is to look at the world and say these are the eight things that seem like they might get us there. Alright? This idea that after just saying we want a performance standard, Congress or the Administration just kind of steps back and just—things don't just happen.

Senator KING. Right.

Mr. GRUMET. And so, you know, I think there are a lot of different ways to slice this. I, because I'm not nearly as sophisticated as the Secretary, think about it in terms of technology: that there's a critical opportunity around nuclear and we can set a real clear goal.

Senator KING. Nuclear storage, carbon capture.

Mr. GRUMET. Exactly.

Senator KING. Hydrogen.

Mr. GRUMET. If this Committee were interested in having a discussion about what those kinds of goals could be and what would be the processes along the way that we could allow ourselves to do.

Senator KING. And if we don't set them, somebody is going to set them, and they will be set sort of randomly. I think this is a better public policy.

Let me follow up, Mr. Faison. I think you had a really good insight that a molecule of CO_2 released anywhere in the world has the same impact. Why did we leave the Paris Accord, which was not a binding treaty, but was at least the first real international effort to acknowledge the problem and to deal with it? Because we could do everything in the world here in the U.S.; we could lower our output by 50 percent or 90 percent, and as you pointed out, it wouldn't matter because China and India are still pumping CO_2 out in record amounts.

So don't we need some international—isn't this an essential part of dealing with this issue?

Mr. FAISON. Well, I'm for the Paris Agreement. Fortunately, we are kind of like artillery officers where we focus on the target rather than stuff going on around us.

Senator KING. But part of the target has to be international, doesn't it?

Mr. FAISON. I agree. I see there are two things to that. Yes, I'm for Paris, I'm for standards, I'm for this government setting—making this a priority and setting ambitious goals. Goals are at the very top of our agenda.

However, if we put standards in place, for example, is Nigeria going to follow them? So there are a lot of countries in the world—Indonesia, India; China may. But I think in order to achieve the kind of decarbonization that we need, we have to deliver the next set of affordable and clean technologies that we can export.

Senator KING. Oh, everywhere. I totally agree with that. But there do have to be standards and we have to realize that this is a global problem. It's not a New England problem or a U.S. problem.

Mr. FAISON. Correct.

Senator KING. Secretary Moniz, just in a few seconds, if you were going to advise us, what should be the top five priorities for federal R&D on energy?

Dr. MONIZ. If I may take the liberty of a brief comment on the global issue, absolutely. But I think there's also an understanding that there will be kind of tiers of compliance in the timeframe with the industrialized nations, which is where most of the emissions are today, needing to lead. The emerging economies may be a little bit behind, and certainly the less developed countries behind as well. So I think that's a clear, clear pathway going forward.

In terms of the areas, well, again, you know, our analysis from over 100 technologies initially, we came down to ten areas that we feel are ones that are underfunded and have great breakthrough potential, and those were storage broadly, many time scales; advanced nuclear; a set of technologies that can serve multiple sectors, like hydrogen, like advanced manufacturing which Senator Stabenow mentioned earlier; but grid modernization.

And something we haven't mentioned today, but integrating all of those platform technologies into the grid and into so-called smart cities, which is also a way of bringing new services to consumers. But that's an area where the new players, like the big data companies—Senator Cantwell has a few near her—and the energy incumbents must find a way of using their skill sets cooperatively.

And finally, a set of these deep decarbonization, large-scale carbon management issues, many of which we've talked about today, and I would just repeat: the whole suite of carbon capture, utilization, and sequestration technologies including new things like—"new things" in the sense that it happens in nature but it doesn't happen at the scale to accelerate—things like biological sequestration: literally, perhaps engineering plants with much deeper root systems, for example, to fix carbon dioxide.

So that's kind of a suite that we would emphasize.

Senator KING. Thank you.

Thank you, Mr. Chairman.

Senator GARDNER. Senator Cortez Masto.

Senator CORTEZ MASTO. Thank you, and thank you all. This has been a great conversation this morning.

Can I ask, just so I have a clear understanding, does anyone on the panel disagree that we should be looking at an all-of-the-above portfolio when it comes to energy geared toward a particular outcome, and that outcome would be decarbonization? Does anybody disagree with that?

[No response.]

Okay, and I agree with it. I think that is why we are here. That is where we could set our long-term mission and goal. As you can see, there are challenges, obviously, and competing interests, political interests.

But I also think, besides the fact that we are here and hopefully going to be setting that standard, don't you also agree that standard is going to be set by the demand? We are hearing of individuals across this country that are demanding that decarbonization, that are demanding those electric vehicles, that are demanding those smart communities and intelligent transportation systems. That is going to help drive this as well, wouldn't you agree?

[Witnesses nod in agreement.]

And I do too. I think we have a perfect opportunity here to really coordinate with that demand and do something. And it starts with the innovation. I absolutely agree that an energy innovation ecosystem is where we as a country should be leading. We should be leading in this space and take every advantage when it comes to investment and incentivization and whatever else we need to do.

Here's the challenge I always hear, and it goes back to, I think, what Ms. Wince-Smith talked about: workforce. As we go down this path, what are our challenges for our workforce of the future, and how do we bring them along with us? What should we be doing to also focus on those workforce needs? And let me start with you.

Ms. WINCE-SMITH. Well, one of the things we need to do on the workforce is really recognize the whole up-skilling that has to be done, because the jobs we're talking about require a degree of literacy in coding and computing and the digitization of the economy, so that's a very different workforce than the 20th century manufacturing workforce of the past.

One thing that is very exciting that's underway in the skilled labor unions is how they are taking the lead on a lot of this training and they are doing it in partnership with large energy companies, and it's that partnership between labor and industry that's advancing the immediate needs. But for the long-term, you know, states need to recognize that while it was unfashionable to support vocational training, we need to reinvent that for the 21st century model.

And the other thing I would add is if you look at our competitors around the world, Germany being a very good example on workforce, they have such a sophisticated strategy really targeting these jobs and putting the co-ops in place to really get the workers that are able to earn high wages. I mean Germany's wage structure is higher than ours and yet you never hear of Germany about not having the workers we need, where we do in the United States.

And Senator, if I may, I wanted to just add something on the issue of the standards and decarbonization, because no one yet has mentioned that global supply chains in which all our companies are operating are increasingly demanding decarbonization to participate in these supply chains. And if you look at what the EU has been doing right now on privacy, no one is going to operate in the EU without having certain privacy. I'm hearing that very soon they are going to be using standards and metrics of decarbonization as perhaps a non-tariff barrier. But if we want the exports of the clean technology that we want to develop from our R&D, we should be at the head of the curve on that. So I wanted to really bring that in because no one had really mentioned that heretofore.

Mr. GRUMET. Senator, if I could just add, I think your two points are actually one and the same because if we have a better vision, we will then change the conduct of the workforce. Right now, joining an energy company is a political decision. Some people will only want to work for solar companies. Some people will only want to work for oil companies. I have the privilege right now of working on the National Petroleum Council's study on energy infrastructure, and the technology innovation that is happening right now in pipelines is phenomenal. And so I think that what will change the workforce, again, is having the sense that we're all part of something that's important and something that the nation cares about.

And, you know, I think what Senator Barrasso and others were able to do with the FUTURE Act, change the conversation around coal in the environmental community. People are having a hard time. It sends a signal that there is a future here. It's not a bad fuel, it's not a good fuel; it's a possibility for the future. And it's had, you know, a real impact on the energy in that community. I think you're having tough conversations.

And so I think, again, if we can get on that kind of sense of we're going to do something great together, you will see people entering the energy field who otherwise would not.

Senator CORTEZ MASTO. Thank you.

I know my time is running out. Secretary Moniz.

Dr. MONIZ. Yeah. I just want to add to what Deborah said in the workforce, and she mentioned the labor unions, with whom I speak quite often. And this is something I know Senator Manchin feels very strongly about and I agree with. Look, what we tend to do is immediately go to the issue of let's put in some retraining dollars in various places, and that's—and I'm not arguing against it. But frankly, the labor unions tell me: Look, we can do the training. Give us the jobs. Give us the new manufacturing.

That's why also looking at advanced manufacturing, what can we do with additive manufacturing? We have a possibility of doing this really across the country, and I think that's the mentality that we need to have.

Senator CORTEZ MASTO. Thank you.

Dr. MONIZ. Get the jobs. And building energy infrastructure, building other infrastructure.

Senator MANCHIN. If I can just say something very quick and add to that. I have experienced it in parts of our state. They just got left behind. And I say, give them a choice. But it takes a while to build a factory. It takes a while to get a factory into operation. During that period of time that it takes, if there is an announcement there is going to be a factory in a certain part of any of our states that is transforming our energy delivery system, they will prepare. We will get people ready. They will go and they will be educated, because they know that job and that paycheck is waiting.

What we have done is, basically, we have eliminated and changed courses, and then we say we are going to go down and retrain. Well, what the heck are you retraining them for? There is nothing coming. There is no hope. They don't want to leave the area. That is where their family is.

That is the problem we run into, and then we get in these divides where our caucuses, whether it be Democrat or Republican, are divided within the whole Senate or the whole Congress.

We don't want to drink dirty water. We don't want to breathe dirty air. We want our kids to have a future. We really do. But they also realize they have to have a job to sustain themselves.

We think we can make this happen and we are hoping that—I am just hoping that, basically, the Green New Deal gets us on a path where we can come together, understanding that is a really lofty goal. Can we accelerate it? I think Martin has talked about acceleration of things happening more quickly than what we ever thought. That is all doable, and I am just hoping that we can find that path. I am worried about the rest of the world unless we find the cost-effectiveness of making sure there is going to be an incentive for them to jump in.

Senator CORTEZ MASTO. Thank you.

Can I make one comment? Because I do not disagree with my colleague, and thank you for the comment, but let me just say this: ten years ago Nevada was known for gaming, entertainment and mining. Now we are an innovation state. That is because we got together as a state and did just what you said: Where is our focus? Where is our future? Where can we bring in new business? What can we do collectively to change it? And we have.

And I think that is what it takes: that combination of the federal level with the innovators, with the private sector and your local governments, everybody coming together. But you have to ask that question first and you all have to work together to figure out where we want to go. And it can be done. I think you are right.

Senator MANCHIN. You have to have a tax base for that. Gambling gave you the tax base——

Senator CORTEZ MASTO. No, it didn't.

Senator MANCHIN. ——for what it cost to diversify.

Senator CORTEZ MASTO. No. That is why we had to diversify.

Senator MANCHIN. No. I am saying that our tax base has been coming from extraction, and when it left, we had a hard time just——

Senator CORTEZ MASTO. I am just telling you, we were hardest hit in the recession, and I am telling you gaming didn't help us. It is the reason why we came together and said we have to focus on another industry.

Senator GARDNER. Once in a while in the U.S. Senate, debate breaks out. That is really good.

[Laughter.]

Senator CORTEZ MASTO. Thank you. Thank you very much. I appreciate the indulgence.

Senator GARDNER. Senator Cantwell.

Senator CANTWELL. Mr. Chairman, I love the lively debate among the panelists, the members, everything. All I can say is the Quadrennial Energy Review and the needs—the needs of our nation for the next four years.

It is good to see all the panelists, including Secretary Moniz, because I think that report just laid out everything that we all are saying again today, which is that we need a workforce. We know what our challenges are moving forward, we know what our needs are, we know we need to invest in technology, and so a very good panel discussion.

I wanted to ask Under Secretary Dabbar and Secretary Moniz a couple of things. You mentioned PNNL. Thank you for mentioning that and the great work that they are doing out there. Obviously we are a region that gets the smart grid. I don't know if it is the marrying of hydro and the technology base or—you would think if you are producing three or four cent kilowatt power, you might not keep looking for efficiencies. But we do, and we keep finding them. I guess maybe that culture really did help us understand how much efficiency, which I think is going to be the juggernaut of the future, can do. Because it doesn't matter what the source of energy is, if you can make it more efficient and deliver it more cheaply, then that is what people are going to do. Being the leader in efficiency is just going to be huge, so I wanted to ask you about the testing. You know, part of the efforts that we need from DOE is how to test storage, how to help utilities at all or other industries test out in real live situations what storage and integration can do, so I want to get your comments on that.

I know Senator Murkowski was probably here earlier. I don't know if she asked about quantum information sciences, but what can we expect from quantum computing to help us in these efforts, if you could, Under Secretary or Dr. Moniz?

Mr. DABBAR. Thank you, Senator.

So from a testing point of view, one of the things I think the lab complex does well is basically the contract research that we do, you know, for people, and I'm going to give you an example. I think our two lead battery—well, I know our two lead kind of battery areas are at NREL and at PNNL. They do slightly different ones, but I'm going to give an NREL example. At NREL, we have a test bed which is funded by the big three auto companies where they jointly got together with our test bed, with our kind of capabilities, to run electric vehicle testing jointly for systems. And we do research on their behalf jointly, that they, kind of, pre-competitive between themselves, where they decided to get together as an American footprint. And I do think we are very much in the lead in front of Europe in particular on this particular topic, in part because of some of the testing that we are able to do.

I think one thing that we do well at PNNL is actually work with the utility industry. I'll give you one particular example. Flow batteries have the ability to get from multi-day sort of storage and some of the things that many people here have been talking about earlier, and actually doing testing of larger-scale deployment working with industry is actually something that PNNL is working on.

So I agree that—and this goes back to sort of the broader lab-to-market points in my earlier testimony of how do we bring people together more and how do we take the basic research and chemistry, for example, in this particular case for PNNL and others, and how do we help bridge it down into a product?

And I think one of the challenges of the lab complex was, historically, culturally it was, we'll build it, and someone will come and grab it from us if it's interesting. And so we have been working, you know, the Secretary, myself and others have been working on actually a bit of a cultural change, which is increasing dialogue so that we have capabilities at the labs to hand it off and to help develop with them paying to a large degree, but using our capabilities and then using our test capabilities in helping to create product.

Senator CANTWELL. Great.

Dr. Moniz, did you have any comments on quantum and where it might take us?

Dr. MONIZ. Well, first of all, there's no doubt there's been, in my view, rather surprising progress in terms of quantum computing. And I want to say that the department I know hosted a meeting that I was told went extremely well last, I think, Friday, on a major new focus in quantum computing that Paul might want to elaborate on.

I mean I think we are a long way from having anything that I would call general purpose applications, but obviously in the near-term there are significant possibilities in terms of encryption and the like. But I think the developments in the physical objects that one needs in quantum computing has been just nothing short of remarkable.

Mr. DABBAR. Yeah. So going back to the grand challenge concept that we were talking about earlier, I can tell you that the bill that you all passed has really ignited a tremendous amount of energy and interest across the country from universities and industry. I was just in Seattle with Microsoft and the President of the University of Washington who have partnered with PNNL just to get it all together in the state to form the Northwest Quantum Nexus where they've jointly come together to try to attack in particular this one chemistry problem at PNNL and bring their various skill sets together.

So as I like to think about what the Department does in part is that we are seed money to try to get the rest of the country—universities, private sectors, states—to work together. And I think there's a number of things. I'll give you a couple of quick points.

We were able to—we are in the process of standing up the first entangled quantum internet ever in the world at Argonne and at Fermi in Chicago. It's a big deal. It is far beyond anything else, what anyone else is doing.

And I'll give you one other one about general-purpose quantum is a ways away, but you all fund—we have at the national lab complex the top supercomputers in the world and we continue to build the next ones. One of the things that we're looking at for post-exascale, so way out there, is actually looking at quantum accelerators, so a quantum computing capacity concurrent with traditional classical computers so that we can concurrently separate problems within the same supercomputer and use basically an analysis of the quantum application for the analysis for the data. Might be better than the portion of the computer that's classical. We are already talking about that.

I'd like to once again thank this Committee and the whole Congress for really jump-starting this in the nation.

Dr. MONIZ. And if I—Oh. Deborah, go ahead.

Ms. WINCE-SMITH. Well, I was just going to add that the quantum initiative and the bill that you passed and what's occurring in the Federal Government and these partnerships is a fantastic way to look at these enabling strategic technology transformations that we need to prioritize on. This is not picking a winner and a loser; this is a global race for leadership in the quantum frontier.

China—I mean if we lose the quantum race to China, there are huge national security implications. And interestingly, the Council on Competitiveness has a very robust group of CTOs and heads of research from our universities, deputy lab directors. We're forming a very strategic partnership with Australia, one of the Five Eyes, because they are also a leader in quantum. So this is, again, an area where we need to come together, use all our assets—DoD, DOE, et cetera.

The other one that I mentioned in my testimony, and I know that Under Secretary Dabbar and Secretary Moniz have done a huge job, is next-generation microelectronics. I was involved in the creation of Sematech, you know, many years ago in the Reagan Administration. Again, we had the opportunity not just to lead beyond Moore's Law but to develop the hardened electronics for cybersecurity and build these systems in the United States. We don't have the manufacturing here, but we can, and that's an area we should put huge federal investment and priority in and build the complex public-private partnerships to take it forward.

Dr. MONIZ. If I could just add a note, it's kind of obvious but I think it deserves explicit statement that I think the Department of Energy—and I go back to when I was in DOE, then of course it was DOE and DoD that jointly kind of came together on the major computing initiatives. And a reason why DOE is so important in this area, of course, is that it's a little bit of an unusual Department in the sense of its major national security responsibilities in addition to its responsibilities in the science and energy realms.

Senator GARDNER. Thank you. Thanks to all of you.

Members will have two days to submit questions for the record. I would ask for your responses as quickly as possible.

Thanks to all of you for your time and testimony today and for the participation of the members. This hearing is adjourned.

[Whereupon, at 11:43 a.m. the hearing was adjourned.]

APPENDIX MATERIAL SUBMITTED

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

QUESTIONS FROM CHAIRMAN LISA MURKOWSKI

Q1. Over the past several years, the Department of Energy has made great strides in coordinating research efforts and encouraging inter-office collaboration. In order to get the greatest use from the taxpayer dollar, what can be done within DOE and across the government to make the most efficient use of resources to accelerate innovation for high priority clean energy technology research?

A1. As a science agency, the Department of Energy (DOE) plays an important role in the innovation economy and encourages collaboration and cooperation between industry, academia, national laboratories and government to create a vibrant scientific ecosystem.

Within DOE, the Deputy Secretary recently established the Research and Technology Investment Committee (RTIC) in response to the Department of Energy Research and Innovation Act, Public Law 115-246. The RTIC will bring together key elements of DOE that support research and development activities to share and coordinate their strategic research priorities, identify potential cross-cutting opportunities in both basic and applied science and technology, and ensure key upcoming decisions are leveraged effectively.

The Grid Modernization Initiative is an example of existing effective management collaboration and resource leveraging across all applied research offices reporting to the Under Secretary of Energy. This initiative enables close coordination of activities between the offices of Electricity (OE), Energy Efficiency and Renewable Energy (EERE), Fossil Energy (FE), Nuclear Energy (NE), Advanced Research Projects – Energy (ARPA-E) and Cybersecurity, Energy Reliability and Emergency Response (CESER) that work on applied technologies that have direct impact on the nation's electric grid.

As RTIC goes forward, some examples of priority research that will be closely coordinated may include energy storage, materials for harsh environments, cybersecurity, and artificial intelligence. Many of these areas are also coordinated across government by lead cabinet departments. For example, as Sector Specific Agency for the energy sector, DOE coordinates with the Department of Homeland Security to secure the nation's energy infrastructure from cybersecurity threats. DOE program offices also have Memoranda of Understanding (MOU) with specific government agencies that have funding and authorities to help with coordination. For instance, EERE has an

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

MOU with the Department of Interior on hydropower. DOE also often works with states to leverage funding resources. Recently, for example, EERE leveraged its advanced vehicle funding with the State of California to develop natural gas engine technologies with lower cost, higher efficiency and reduced emissions.

In addition, DOE and the National Laboratories hosted several key meetings with industry on important energy topics, called the XLab Summits. These summits convene key industry representatives in a particular energy related technology, to showcase the strong technical resources and capabilities of the 17 National Laboratories. The events also clarify how the National Laboratories can be leveraged by private companies, investors, universities and other organizations as a source of innovation. The first two summits covered energy storage and grid modernization.

Q2. I believe that microgrids offer an enormous opportunity for increasing the deployment of various clean energy technologies – from micro-reactors and marine hydrokinetics to wind and solar. The Department should increase efforts in this area to conduct more microgrid systems research that will de-risk microgrid technologies and emerging micro-generation options. It should build off the great work of the Grid Modernization Lab Consortium to take advantage of the early deployment opportunities that exist in today's operating microgrids, like the many in my home state of Alaska.

Q2a. What do you believe is the value proposition for microgrids in accelerating our clean energy future?

A2a. DOE recognizes the important role microgrids play in accelerating the deployment of clean energy technologies, as well as the need for research and development (R&D) to de-risk microgrid-enabling technologies to allow for broad deployment. Microgrids provide value by ensuring energy supply for critical loads, controlling power quality, and providing reliability and resilience at the local level by developing technologies to help coordinate and manage distributed and renewable energy sources with "smart" loads. In addition to providing value at the local level, microgrids can also provide grid services to the bulk power system. The value proposition of a microgrid clearly supports all six attributes defined for a modernized grid: reliability, resilience, security, flexibility, affordability, and sustainability. These attributes, along with development of clean energy generation technologies, will accelerate the use of cleaner energy sources in our Nation's power system.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

Q2b. Should the Department conduct an amped-up crosscutting microgrid research program to take advantage of these opportunities?

A2b. The FY 2019 laboratory call to the Grid Modernization Laboratory Consortium (GMLC) under the Grid Modernization Initiative (GMI) includes microgrid research opportunities explicitly addressing energy storage and system flexibility, one of the GMI's focus areas. This topic was developed through close collaboration between DOE's applied energy offices (Offices of Electricity; Energy Efficiency and Renewable Energy; Nuclear Energy; Fossil Energy; and Cybersecurity, Energy Security, and Emergency Response). This work will build on earlier GMLC microgrid projects like RADIANCE in Cordova, AK. Based on the evident interest of many DOE offices in microgrid research opportunities, DOE will make a concerted effort to strengthen the crosscutting aspect of its microgrid research to engage and involve other DOE offices at a higher level than has been achieved to date.

Q3. In your role, you ensure that basic science research capabilities are leveraged to answer essential questions that might otherwise limit applied energy research. Can you provide us with some examples of how the Department has built bridges between the science and applied energy offices to provide support for clean energy technologies?

A3. The Department facilitates coordination between DOE R&D programs through a variety of Departmental activities at the program office levels, including joint participation in research workshops, strategic planning activities, solicitation development, and program review meetings. The Office of Science (SC) also coordinates with DOE technology offices in the Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program, including topical area planning, solicitations, reviews, and award recommendations.

Department program managers regularly participate in intra-departmental meetings for information exchange and coordination on solicitations, program reviews, and project selections in the research areas of biofuels derived from biomass; solar energy utilization, including solar fuels; building technologies, including solid-state lighting; advanced nuclear energy systems and advanced fuel cycle technologies; vehicle technologies; improving efficiencies in industrial processes; and superconductivity for grid applications. These activities facilitate cooperation and coordination between SC and DOE technology offices and defense programs. DOE program managers from basic and applied programs have also established formal technical coordination working groups that meet on a regular basis to discuss R&D activities with wide applications. Likewise, DOE technology office personnel participate in reviews of SC research, and SC personnel participate in reviews of research funded by the technology offices.

Co-funding and co-siting of research by SC and DOE technology programs at the same institutions has proven to be a valuable approach to facilitate close integration of basic and applied research. In these cases, teams of researchers benefit by sharing expertise and knowledge of research breakthroughs and program needs. The Department's national laboratory system plays a crucial role in achieving integration of basic and applied research. Additionally, in January, DOE established a Research and Technology Investment Committee (RTIC) in response to requirements of the Department of Energy Research and Innovation Act of 2018 for greater collaboration and coordination across the DOE programs. The purpose of the RTIC is to convene key leadership and management across the Department elements that support research and development activities to share and coordinate their strategic research directions, identify potential cross-cutting opportunities in both basic and applied science and technology, and more effectively inform Departmental priorities and initiatives.

Q4. Swedish mining company LKAB and its Norwegian partner are developing a carbon dioxide-free process for steel production and mining. Iceland has a "no waste" mantra, including a carbon recycling plant that turns carbon dioxide from a nearby geothermal power plant into methanol for vehicle fuel. There is a lot of energy innovation happening in the Arctic, often by necessity. Is the United States doing anything similar to these types of activities, and are there other areas where we could be learning from our international partners?

A4. The Department of Energy is engaged in significant energy innovation efforts in the Arctic. A few specific examples of what DOE is doing in the Arctic include:

- Office of International Affairs: coordinates a DOE-wide Arctic Energy Working Group, which develops consolidated recommendations on Arctic Policy related to promoting international U.S. energy dominance. These recommendations represent inclusive DOE equities and are provided to department leadership and the National Security Council for interagency engagement.

- Office of Science: basic research and measurement in Alaska, exascale computing and Earth systems modeling, and next generation ecosystem research including experiments to predict the evolution of permafrost.

- Office of Indian Energy: works with Alaska Native populations to promote tribal energy development, including providing grants for energy generation and micro grid projects, and technical assistance to help bring electrical power to remote villages, with a specific goal of reducing energy costs, which is a major issue for the Alaska Native communities we serve.

- Office of Fossil Energy: leads federal R&D for gas hydrate research, with a focus on characterizing, evaluating and confirming the potential for gas hydrates production on the North Slope; funds heavy oil research in Alaska; and is coordinating the drafting of a supplement to the National Petroleum Council's 2015 Arctic Potential study. It will also handle the Alaska LNG export authorization.

- Office of Electricity and Energy Efficiency and Renewable Energy (EERE): focuses on micro grid and resilience programs, for example by providing villages in Alaska with decision support tools for designing micro grids that significantly reduce diesel fuel consumption, while improving energy system reliability and resilience. In addition, demonstration and deployment of advanced micro grid-enabling technologies, as well as business cases analyses for micro grid investments, have been conducted in support of Alaskan communities.

- Since 2014, EERE's Water Power Technologies Office (WPTO) has supported unique research and testing capabilities in marine energy at the University of Alaska Fairbanks (UAF) and through UAF's partnership with the Pacific Marine Energy Center, formerly known as the Northwest National Marine Renewable Energy Center. More recently, WPTO selected the Ocean Renewable Power Company of Portland, Maine for continued funding of its partnership with the Igiugig Village Council to conduct scaled up in-stream hydrokinetic turbine testing. The Pacific Northwest National Laboratory will assist the Village in addressing permitting and environmental barriers. In addition, the Solar Energy Technologies Office partners with UAF and Sandia National Laboratory to study the effects of snow on photovoltaics system performance and whether photovoltaic modules and systems can be specifically designed to perform better and last longer in snowy climates. The project will examine the adhesion of snow and ice to module surfaces, and will develop models to predict system level energy output for a variety of module technologies and racking configurations.

Q5. During the recent Arctic Frontiers Conference held in Norway, a Swedish Arctic energy company CEO announced a major project developing zero-carbon mining. He anticipates mining and tunnel operations being carbon-free in the next five to ten years at a specific site. Mining is certainly a challenging sector from an emissions perspective. Are there technologies being investigated in the U.S. that could lower carbon emissions from mining operations?

A5. The Office of Fossil Energy (FE) has engaged with miners in many of the workshops conducted on coal beneficiation. FE is aware of several autonomous mining technologies that are being investigated that could have the potential of reducing carbon emissions and improving the safety of miners.

Q6. What are the most promising developments in carbon capture, utilization, and sequestration innovation and can you tell me more about the role these technologies will play in the future? Furthermore, in order to get the Department of Energy set up for success in developing these technologies, what policy changes would you suggest?

A6. The Department of Energy's (DOE) carbon capture, utilization, and storage (CCUS) research and development (R&D) portfolio is working to reduce the cost of carbon capture, develop viable carbon utilization alternatives, and ensure safe, permanent storage of carbon dioxide (CO2) in geologic formations. This portfolio has advanced several capture technologies (advanced membranes and solvents) to the pilot-scale which show potential to reduce the cost of capture to $30/tonne by 2030. This is a 70% reduction ($100 to $30) in the cost of capture. Having large volumes of CO2 available at $30/tonne significantly expands the opportunities for enhanced oil recovery, carbon storage, and chemical manufacturing production the United States. DOE has also funded several technologies that utilize CO2 to produce fuels, chemicals, and building materials.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

The majority of these technologies are early-stage R&D focused on ensuring that the products are of the same quality, cost-competitive with other products on the market, and reduce the environmental footprint. Carbon storage R&D activities have shown that CO2 can be safely and effectively stored in various geologic formations. Future efforts are focused on continuing to optimize the storage process by applying techniques such as machine learning to better understand the subsurface.

DOE's R&D efforts provide the technical and scientific information for policymakers to make informed decisions that ensure there is market pull to encourage adoption and uptake of these technologies.

Q7. ARPA-E plays an essential role in the innovation ecosystem by investigating solutions to specific challenges that stand in the way of full commercial development of all types of clean energy technology. ARPA-E goes beyond the limits of the other offices of DOE and to the places that the private sector cannot afford to go – effectively bridging a valley of death in technology development. Can you tell us more about how ARPA-E can partner with the rest of DOE to solve the challenges in developing, de-risking, and ultimately lowering the costs of important clean energy technologies?

A7. As directed by its authorizing legislation, ARPA-E coordinates activities "to the maximum extent practicable" with DOE programs and laboratories to avoid duplication. See 42 U.S.C. § 16538(i). The proposed elimination of ARPA-E promotes more effective and efficient use of taxpayer funds, and positions DOE to incorporate elements of ARPA-E into the existing Applied Energy Offices to support a more integrated energy R&D strategy. The elimination enables a streamlining of Federal activities and ensures more focus on early-stage R&D, where the federal role is strongest, and reflects the private sector's role in commercializing technologies.

Q8. As we consider ways to encourage more U.S. investment in energy technology innovation, how do you view the potential roles for technologies like off-shore wind and marine renewable energy sources like wave and tidal?

A8. Off-shore wind and marine energy can play a vital role in our "All-of-the-Above" energy strategy. With more than 50% of the population living within 50 miles of coastlines, and the coastal and Great Lakes states accounting for nearly 80% of U.S. electricity demand, there is vast potential to provide clean, renewable electricity to communities and cities across the United States using offshore wind and marine and hydrokinetic (MHK) technologies. For offshore wind alone, these coastal load centers have a technical resource potential twice as large as the nation's current electricity use. Analyses of wave energy potential in the Pacific have shown that developing just 1/6th of the available wave energy across the five Pacific states could satisfy roughly 10% of those states' electricity demand, power more than 5 million homes, and support roughly 33,000 jobs.

According to the National Renewable Energy Laboratory's (NREL) Offshore Wind Technologies Market Update published in 2018, the United States currently has 25.4 GW of offshore wind in the development pipeline, with 2 GW expected to be operational by the end of 2023. In the next two decades, offshore wind has the potential to provide power to the East and West Coasts, Great Lakes, Gulf of Mexico, Alaska, and Hawaii by utilizing both fixed-bottom and floating offshore wind technologies. Because of the unique coastal and ocean environment in the United States, which includes deep water and hurricanes, further innovations will be required to realize low-cost installation of wind in these regions. DOE is currently funding two Advanced Technology Demonstration Projects and the National Offshore Wind R&D Consortium to conduct research and development activities to address technological barriers and lower the costs and risks of offshore wind in the United States.

While Marine Hydrokinetic technologies are higher cost and further away from utility-scale commercialization than offshore wind systems, there have been significant achievements in recent years through innovative mechanisms like the 2016 Wave Energy Prize. Advances will continue through efforts like the Waves to Water Prize, announced by the Assistant Secretary of the Office of Energy Efficiency and Renewable Energy on February 25, 2019, which is focused on incentivizing the development of modular, rapidly deployable wave-powered desalination systems. This new prize and future efforts will be focused on nearer-term opportunities for marine energy technologies to serve the energy needs of other maritime markets, including potentially powering subsea sensor systems and recharging autonomous underwater vehicles used for both scientific and national security missions, and providing power to future deep-water aquaculture farms. These and other potential high-value opportunities for the use of MHK technologies were detailed in a draft report released for public comment in 2018.[1]

[1] https://eere-exchange.energy.gov/FileContent.aspx?FileID=fcf63beb-3f9d-4e8b-9c35-aa1d746fef6d

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

Q9. Micro-reactors have the potential to lower the cost of electricity, increase reliability and resilience, and decrease emissions for many challenging applications. These advanced reactors would compete with the diesel generator market and could transform life for remote communities, provide stability to military installations, and even make mining or mineral development operations economically viable.

Q9a. What potential do you see in micro-reactors?

A9a. The Department believes there is potential for micro-reactors to provide the commercial and defense sectors with a clean, reliable and resilient energy supply technology. These higher temperature, enhanced safety, and longer operating micro-reactor concepts could be capable of electricity generation, district heating, industrial process heat, water desalinization and purification, as well as hydrogen production. The Department believes micro-reactors could provide remote communities and industrial applications with reliable electricity; resilient and reliable energy supplies for remote and forward military base operations; and a source of reliable and clean electricity during disaster and emergency relief operations.

Q9b. What are your chief policy concerns relating to getting these micro-reactors to market?

A9b. Micro-reactor developers have identified licensing issues that could affect near-term micro-reactor deployment. The Department and the micro-reactor developer community have identified licensing areas unique to micro-reactors.

These areas include:

- Transportation requirements for delivering fully-fueled, factory-manufactured micro-reactors from the factory to the operating site, and subsequent transportation of shutdown micro-reactors to the manufacturer or to other operating sites;
- autonomous operation, remote monitoring, and minimized staffing and emergency planning zone requirements for micro-reactors;
- fuel licensing and qualification requirements and applicability of NRC regulations to unique advanced fuel designs, including use of high-assay low enriched uranium (HALEU) fuels;
- approval of novel enhanced safety system designs that differ from the legacy light water reactor (LWR) designs upon which existing regulations are based; and

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

- pathways to license a first-of-a-kind micro-reactor demonstration unit as a research and test reactor.

Owners, licensees, and operators of advanced nuclear plants will struggle to develop and finance micro-reactor projects in remote locations. Financial risks increase the farther away the micro-reactor plant is from a known and constant power demand.

Q10. I understand that today's technologies are finding economic applications on the grid and in electric vehicles. We have heard at previous hearings about the limitations of today's technologies and the importance of developing next-generation storage.

Q10a. What are the most promising energy storage technologies under development today?

A10a. The Office of Electricity (OE) Energy Storage program, Office of Science, Advanced Research Projects Agency-Energy, and Office of Energy Efficiency and Renewable Energy (EERE) are actively pursuing energy storage research and development (R&D) efforts across a wide range of battery chemistries, new pumped storage hydropower designs, advanced fuel cells, and thermal storage. EERE and OE also support R&D to increase the flexibility and resilience of the electric system through technologies and integrated systems operations that provide storage-like capabilities—for example power electronics that allow wind and solar power to provide frequency regulation or other grid services, microgrids that actively balance resources, and dynamically shifting loads within buildings to match generation patterns. Focused R&D is needed to improve these capabilities and better manage them, both at an individual technology level and as an integrated system. The request proposes work related to materials research, device development, safety and reliability, grid analytics, and demonstrations, each focused on reducing the technology barriers to energy storage deployments to meet these needs.

At present, electrochemical storage technology offers some of the most flexible solutions that allow bidirectional flow of the electric energy and can be strategically placed throughout the electric grid. However, the cost of high-energy high-capacity batteries remains relatively high in large part due to the cost of materials used by existing technologies. Much of the electrochemical storage R&D proposed efforts are focused on utilizing earth-abundant materials (such as carbon-based organics, sodium, and zinc) to enable the next generation of low-cost storage technologies with U.S. sourced materials.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

For grid-scale electrochemical storage, R&D efforts include; advanced flow batteries using water-soluble organics to store electricity enables tremendous opportunity for highly flexible storage systems that can serve short-duration power quality applications and longer-term applications including time shifting of renewable generation. Sodium, as the seventh most abundant element in the earth's crust, has the potential to be a lower-cost alternative to today's lithium-ion batteries while eliminating supply-chain constraints from sensitive nations. Finally, reversible zinc-based storage technologies—based on the alkaline batteries found in every household—could allow sub-$80/kW grid storage solutions to be developed that use an already existing U.S. manufacturing base. Other electrochemical technologies are also in development for grid-scale storage—the most promising candidates need to similarly possess both low-cost starting materials and a pathway to high-volume manufacturing.

Electrochemical storage is not the only technology the Department is pursuing for electrical energy storage. Other technologies that allow bidirectional electrical energy storage include new closed-loop pumped storage designs with lower up-front costs and environmental impacts, and unitized hydrogen fuel cell stacks that can store and discharge electricity at scale.

For vehicles, advances continue to be made in lithium-ion technologies, as well as charging infrastructure that simultaneously reduces charging time while providing additional flexibility to the power grid.

Storage R&D occurs in many parts of DOE, with experience and projects that can be leveraged across offices. In the FY 2020 President's Budget, DOE proposed an Advanced Energy Storage Initiative (AESI) that reaches across the Department and combines energy storage R&D with research on system flexibility that can provide some benefits similar to physical energy storage systems. AESI will build an integrated DOE R&D strategy and establish aggressive, achievable, and comparable goals for cost competitive energy storage services and applications.

Q10b. How could efforts be accelerated for these important technologies?

A10b. While several of DOE's National Laboratories have conducted significant and groundbreaking R&D work in energy storage, much of the focus has been on fundamental research on battery technologies for transportation applications. For new grid-scale energy storage technologies, three areas are critical to accelerate their adoption by utilities and other stakeholders:

- Independent validation of the expected lifetime and performance of new technologies must be conducted under realistic grid operating conditions to de-risk new technologies and enable user confidence;
- rigorous grid performance requirements must be propagated to all stages of storage development, from materials, to prototypes, to functional devices, thereby greatly reducing the developmental timeline; and
- enhanced coordination between DOE and the storage R&D communities is critical to solve key crosscutting challenges and to lower the science and technology barriers for new storage systems.

Q11. We have already seen China take solar technology that was invented in U.S. labs and commercialize it at scale in a way that floods international markets and increases China's position as a dominant exporter of clean energy technology. We are watching them replicate this success with battery technology and the critical mineral supply chain that underpins both technologies. Finally, China is pushing aggressively on advanced nuclear with the intention of dominating global nuclear markets as well.

A11. The Department of Energy (DOE) is engaged in significant innovation efforts on solar, batteries and advanced nuclear.

Lithium Ion Battery Manufacturing

Lithium-ion battery manufacturing was commercialized at scale overseas well before there was significant U.S. domestic manufacturing. Low returns, subsidized production, vertical integration, and manufacturing know-how allowed Asian nations (Japan, Korea, China) to dominate battery manufacturing, starting in the late 1990s. However, successful U.S. research and development has enabled a significant increase in domestic manufacturing capacity in recent years. Specifically, the United States now produces more lithium-ion batteries than Japan and South Korea (on a gigawatt-hour basis), has doubled its announced domestic capacity, and has achieved an economic impact[2] that is comparable to China. Research has shown that the United States can compete globally in electrode production, cell manufacturing, and pack assembly, which represent more than 60 percent of the direct economic value.

Additionally, lithium-ion batteries for electric vehicles and large format stationary installations are typically manufactured near the markets they serve. High transport costs and geopolitical conditions make importing from Asia cost-prohibitive. Growing domestic demand for lithium-ion batteries will likely be accompanied by a growing domestic lithium-ion battery manufacturing capacity. However, national policies and regulations in China and Europe will likely drive their near-term EV market to a higher volume than the United States. As a result, it is most likely that China will be the leading battery manufacturer, as companies source locally. The United States can still increase its volume of manufacturing as demand grows in North America for EVs. It can also maintain technological leadership through continued early stage research and innovation, which can translate into high value aspects of the battery supply chain.

Within the Department's Office of Energy Efficiency and Renewable Energy (EERE), the Vehicle Technologies Office (VTO) funds R&D to significantly reduce the cost, weight, volume, and charge time of plug-in electric vehicle (PEV) batteries, and R&D that seeks to reduce dependence on critical materials. VTO R&D has contributed to the reduction in battery costs by over 80 percent in the last 10 years, from just over $1,000/kWh to $197/kWh (2018), and has reduced the amount of cobalt in a battery (a critical material) by over 80 percent. More research could eliminate critical materials content and make PEVs affordable and accessible to all Americans. VTO research focuses on 1) reducing the cost of electric vehicle batteries by more than half, to less than $100/kWh while also eliminating or reducing cobalt levels through new chemistries (see more details below), 2) increasing the PEV range to 300 miles, and 3) decreasing the PEV charge time to less than 15 minutes – all by 2028.

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[2]National Renewable Energy Laboratory (NREL) Clean Energy Manufacturing Analysis Center (CEMAC). Benchmarks of Global Clean Energy Manufacturing - Chapter 5. NREL/TP-6A50-65619. January 2017 https://www.nrel.gov/docs/fy17osti/65619.pdf

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

The United States has improved its global competitiveness on EV battery technology by developing global research and innovation leadership.[3] It will be critical that the United States maintain that leadership through a combination of fundamental research and continued close cooperation with industry, which can facilitate adoption of innovation. In addition to battery chemistry, it will be important for the United States to continue to develop innovative battery manufacturing technology.

Lithium-ion Battery Critical Materials

As research continues to lower cost, the global demand for lithium-ion batteries for a variety of applications, including consumer electronics, defense applications, grid storage, and electric vehicles, is expected to grow. Though this growth represents a great opportunity, it creates a potential supply chain constraint on the critical materials needed to produce lithium-ion batteries. Cobalt is of particular concern due to high domestic import reliance (72 percent) and geopolitical dynamics: 58 percent of the global cobalt supply comes from the Democratic Republic of Congo and over 50 percent is refined in China. Cobalt chemical production is even more highly concentrated in China.

EERE, through both VTO and the Advanced Manufacturing Office (AMO), is working to address these issues. AMO work focuses on elemental recovery, and VTO efforts focus on recovery, recycling, and reuse of lithium-ion battery components and materials.

The Critical Materials Institute, an AMO energy innovation hub at DOE's Ames Laboratory, has addressed critical materials, including lithium and cobalt, through research and development in four areas: diversifying supplies, developing substitute materials, reuse and recycling, and crosscutting research. Unconventional resources are one avenue to diversify supplies and include geothermal brines; patent applications have been filed on extraction of lithium and separation of lithium-chloride from geothermal brines. Additionally, elemental extraction and new pathways (disassembly and remanufacturing) from electronic waste, including but not limited to lithium-ion batteries, are being investigated to advance reuse and recovery science and technology.

[3] https://www.energy.gov/eere/vehicles/articles/fotw-1057-november-26-2018-one-million-plug-vehicles-have-been-sold-united

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

VTO has increased its focus on lithium-ion battery recycling to support environmental, economic, and supply chain reliability objectives. Through a reliable and self-sustaining recycling infrastructure, the United States can decrease its dependence on foreign sources to support the domestic lithium-ion battery industry. VTO's strategy is three-fold: research to reduce the amount of cobalt needed for next-generation batteries, increased focus on the economic recovery of lithium-ion batteries through the ReCell Center, and optimized logistics for the domestic collection of spent batteries through the Lithium-Ion Battery Recycling Prize. Together, this strategy has the long-term potential to supply over 60 percent of the material for next generation batteries.

Solar

The solar energy industry is now considered significant, with more than one million systems in operation throughout the country, producing enough solar energy to power 10 million homes.[4]The industry is projected to triple in size over the next five years.[5] Recent growth in solar installations was enabled by intense competition and rapidly declining module prices. From 2013 to 2016, average PV module prices fell by 51 percent.[6]

The solar industry is a proven incubator for job growth in the United States, with a nearly 160 percent increase in less than a decade. Currently, there are more than 242,000 U.S. solar workers.[7] Most of the jobs added by the industry are installation jobs that pay $24/hour for an entry-level electrician position, which is more than 3 times higher than the federal minimum wage. Median wages for a mid-level electrician is $32/hour.
Solar jobs by sector include:

- Manufacturing: 34,000
- Installation/Project Development: 155,000
- Wholesale Trade & Distribution: 29,000
- Operations and Maintenance: 11,000
- Other: 13,000

[4] Solar Energy Industries Association. Solar Market Insight Report. 2018. https://www.seia.org/us-solar-market-insight.
[5] *Supra*, n. 1.
[6] SPV Market Research. Photovoltaic Manufacturer Capacity, Shipments, Price & Revenues 2016/2017.
[7] The Solar Foundation. 2018 National Solar Jobs Census. 2019. https://www.thesolarfoundation.org/national/

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

While the research, development, and initial manufacturing scale-up of solar photovoltaic (PV) technologies was pioneered in the United States, the production of silicon solar cells and modules has largely been based in China. Nearly 90 percent of panels installed in the United States today are made outside our borders.[8]

In 2017, the United States accounted for 10,600 MW of annual PV demand – 11 percent of global demand – making it the second-largest market globally after China.[9] The United States is the second largest manufacturer of polysilicon, the key precursor material to silicon solar cells, in the world, hosting 17 percent of global manufacturing capacity in 2014. However, domestic manufacturing capacity of other segments of the crystalline silicon PV supply chain is lower: 2 percent of modules and less than 1 percent of cells and wafers.[10]

Early stage research and new innovations are key to strengthening the U.S. manufacturing position. Over the past 10 years, the cost of solar technologies have declined dramatically. In September 2017, DOE announced that the solar industry achieved its aggressive cost target of $0.06 per kilowatt-hour for utility-scale solar three years ahead of schedule. Research and technology investments from DOE's Solar Energy Technologies Office (SETO) have reduced costs in every stage of the "going solar" process. From developments in cadmium telluride that a major U.S. photovoltaics manufacturer uses, to racking systems that reduce installation time, to modules that have 25-year guarantees, and to faster interconnection analysis, SETO's early-stage research investments have helped to drive down costs and make it easier and faster for more Americans to choose solar.

Now, as the solar industry made rapid progress toward the 2020 targets, DOE committed to reaching new cost targets for the upcoming decade, which support greater energy affordability by cutting the cost of solar electricity an additional 50% between 2020 and 2030. These new cost targets will spur the innovation needed to make the U.S. more competitive in the global market.

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[8] Energy Information Agency. "2016 Solar Photovoltaic Cell/Module Shipments Report." 2016. https://www.eia.gov/renewable/annual/solar_photo/pdf/2016_tables.pdf
[9] International Energy Agency. "2018 Snapshot of Global Photovoltaic Markets." 2018. http://www.iea-pvps.org/fileadmin/dam/public/report/statistics/IEA-PVPS_-_A_Snapshot_of_Global_PV_-_1992-2017.pdf
[10] National Renewable Energy Laboratory. "Benchmarks of Global Clean Energy Manufacturing." 2017. https://www.nrel.gov/docs/fy17osti/65619.pdf

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

In June 2018, SETO launched the American-Made Solar Prize to revitalize U.S. solar manufacturing. The Solar Prize supports entrepreneurs as they develop transformative technology ideas into concepts and then into early-stage prototypes ready for industry testing. The Solar Prize received a high number of quality submissions from more than 165 innovators around the country. On February 27, 2019, the U.S. Department of Energy announced the results of the Ready! Contest. Twenty teams from 15 states were named semifinalists and each won $50,000 to continue development of their solutions.

Advanced Nuclear

It is critically important that the United States remains a leader in commercial nuclear technology. State-owned companies from Russia and China pose the stiffest competition to United States commercial companies and make it very difficult for U.S. nuclear technology companies to compete in the global nuclear market place. Nuclear energy is an essential element of the Nation's diverse energy portfolio required to sustain the U.S. economy and support our national and international goals and objectives. It is an essential element of our nation's electricity sector, grid reliability and resiliency, and national security. However, the Administration recognizes that the U.S. nuclear energy sector is under historic downward pressure, has seen a significant degradation in its manufacturing base, is facing tough competition in the international market, and has lost a tremendous share of its once dominant global market presence.

Enhancing the long-term competitiveness of the existing U.S. reactor fleet is of key importance as a strong domestic fleet of nuclear reactors forms a base market for our commercial nuclear technology vendors. A strong domestic market base is necessary to maintain manufacturing, workforce, and supply chain capabilities so U.S. companies can successfully compete in the international nuclear technology market. Russia and China's state-owned entities have the highest levels of support within their governments as these state-owned entities endeavor to win international nuclear reactor deals. These nuclear reactor deals provide Russia and China the ability to gain strategic influence through these exports to newcomer countries. [11] Russia and

[11] United States. (2017) The national security strategy of the United States of America. Washington: President of the United States. Page 2 ("China and Russia challenge American power, influence, and interests, attempting to erode American security

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

China's spheres of influence increase as they continue to gain nuclear market share. These governments devote significant resources such as supply financing, major in-country infrastructure projects, educational programs, and other capabilities to support their state-owned nuclear companies as deals are being developed, which presents competitive challenges to the U.S. nuclear industry.

The loss of the United States nuclear industry would impact the United States as a whole by reducing its ability to influence other countries to select safe, secure nuclear technologies. If the United States does not have nuclear technology offerings other countries will see little reason to seek the advice of the United States with regards to nuclear technology, which cedes US influence.

The Nuclear Energy Institute reports that U.S. nuclear industry currently employs nearly 100,000 people[12]. This number grows to 475,000 when secondary jobs in communities surrounding nuclear power plants are included.[13]

The U.S. nuclear technology industry must innovate to compete in the global market place. There are multiple (approximately 50) United States based advanced nuclear technology companies that are developing the most innovative technologies available in the world. The Department is supporting these technology innovators by making research, development, and demonstration funding available to advance their technologies. Through the Gateway for Accelerated Innovation in Nuclear (GAIN), the Department of Energy's (DOE) Office of Nuclear Energy (NE) is working closely with the private sector to establish effective private-public partnerships focused on accelerating the development and deployment of innovative nuclear technologies. The support of the Department of Energy and its world-class laboratories is essential to the U.S. nuclear industry as it works to bring forth new innovative technologies.

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and prosperity. They are determined to make economies less free and less fair, to grow their militaries, and to control information and data to repress their societies and expand their influence."), available at https://www.whitehouse.gov/wp-content/uploads/2017/12/NSS-Final-12-18-2017-0905.pdf. *See also* https://www.cfr.org/blog/america-risks-missing-out-global-nuclear-power-revival?utm_medium=social_share&utm_source=emailfwd and https://partnershipforglobalsecurity.org/civil-nuclear-competition-climate-and-global-security/.

[12] https://www.nei.org/advantages/jobs
[13] https://www.nei.org/advantages/jobs

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

NE is working to revive, revitalize and expand the Nation's nuclear energy enterprise by enhancing the long-term competitiveness of the existing U.S. reactor fleet, supporting the establishment of an advanced reactor pipeline of new technologies, supporting the establishment and maintenance of key national strategic fuel cycle infrastructure, and rebuilding U.S. influence in the international commercial nuclear market place. The Office of Nuclear Energy has taken leadership of an inter-governmental program we call Team USA. A coordinated, whole-of-government "TeamUSA" approach is needed to support U.S. industry as it competes for international projects. This includes policy development that supports nuclear commerce, export promotion, advocacy from the Commerce Department, financing support from EXIM Bank, R&D support from DOE, and high-level diplomatic engagement from the Department of State.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

QUESTIONS FROM RANKING MEMBER JOE MANCHIN III

Q1. There are a number of federal players involved in the advancement of CCUS technology between R&D, tax credits, transmission, loan programs, etc. I want to ensure that, at the federal level, we are optimizing our ability to advance CCUS technology and commercialization.

What are the primary barriers the Department of Energy is working to overcome with its carbon capture and storage R&D agenda?

A1. There are several barriers that the Department of Energy's (DOE) research and development (R&D) program is working to address, specifically: 1) reducing the cost of carbon capture, utilization, and storage (CCUS), particularly the cost to capture carbon dioxide (CO_2); 2) reducing the energy penalty associated with carbon capture; 3) providing viable carbon utilization alternatives to monetize CO_2 which can help further reduce CCUS costs; and 4) ensuring safe, permanent storage of CO_2 in geologic formations. DOE is a global leader in CCUS, sponsoring twenty-five R&D projects and three demonstration projects safely and permanently storing CO2 in different geologic formations. In addition, industry has stored over 600,000 million tons in oil fields during enhanced oil recovery operations.

The Bipartisan Budget Act of 2018 substantially increased and extended the 45Q tax credit, increasing the applicable value of carbon dioxide (CO_2) stored in geologic formations to $50 per ton, and the applicable value of both CO_2 used for enhanced oil recovery operations as well as CO_2 "utilized" and permanently removed from the atmosphere to $35 per ton. DOE stakeholders have expressed interest in using this tax credit to help finance CCUS projects, but they have also raised concern about the uncertainty regarding requirements for construction to commence prior to January 1, 2024 will prevent qualified facilities from meeting the statutory deadline required by recipients of the 45Q tax credit . In response to those concerns, DOE is prepared to work with the Treasury Department as outlined in a December 13, 2018 letter from Secretary Perry to Secretary Mnuchin:
https://www.energy.gov/sites/prod/files/2019/02/f59/Letter%20from%20Secretary%20Perry%20-%2045Q.pdf

Q2. One of my concerns is ensuring that the Department of Energy and our national labs are fostering innovative technologies from concept all the way to commercialization. It seems to me that our national lab system provides the perfect environment to connect interrelated technologies that can be developed in collaborative way with businesses and universities. It is often these partnerships that allow maturing technologies to succeed.

How can we ensure that funding to labs is not spread too thin and we are focused on getting promising technologies across the finish line?

A2. The Department of Energy is committed to spurring discovery and innovation at our National Laboratories ("Labs"), and ensuring that America retains its preeminent place in scientific research and technological commercialization in an increasingly competitive world. DOE recognizes the need for an increased reliance on the private sector to fund later-stage research, development, and commercialization of energy technologies by fostering collaboration between Labs, universities and companies, and the need for innovative funding models to accelerate and ease technology development and commercialization of cutting edge research and innovation.

The Department continues to administer an array of programs that support the development of public-private partnerships which help ensure promising technologies get across the finish line. In addition to streamlining and making flexible the various mechanisms available to the Labs for collaboration with partners to mature R&D, DOE administers several programs specifically targeting technology transitioning from the Labs to the finish line. The Secretary designated the Director of the Office of Technology Transitions (OTT) as the Department's Chief Commercialization Officer (CCO). The CCO will strive to expand commercialization solutions and appropriately address barriers to commercializing Lab technologies. Some examples of activities supported by DOE program offices, and led by the CCO, which foster moving innovative technologies toward commercialization include: the Technology Commercialization Fund (TCF), Energy I-Corps, Lab Partnering Service (LPS), and InnovationXLab Summits.

To maximize the impact of federal research and development investments in its laboratories, the Department is tasked with promoting innovations to advance U.S. economic competitiveness. This is accomplished through mechanisms such as Cooperative Research and Development Agreements (CRADAs), Strategic Partnership Projects (SPPs), and licensing of intellectual property. In late 2017, DOE made permanent Agreements for Commercializing Technology (ACT), a tool (piloted for six years prior) that provides the contractors operating the Labs a more flexible way for industry to work with the Labs on research and technology projects. We've also expanded the use of ACTs by authorizing a new pilot program called FedACT. This program extends the benefits of ACT to those who wish to partner with DOE Labs on federally-funded projects. DOE has also taken a number of approaches to increase the impact of CRADAs and SPPs. In November 2018, DOE announced the approval of the Laboratory Agreement Processing Reform initiative, which is designed to streamline the ability of contractors at our Labs to enter into certain lab partnering agreements within a DOE-approved portfolio of routine work. We anticipate this will significantly reduce the processing time for agreements in the approved portfolio, enabling the Labs to concentrate on more complex, potentially higher-impact transactions. DOE also announced a Liability Reform initiative, which provides more flexibility for the Labs to address indemnity requirements. Indemnity requirements are a common barrier to private sector engagement, so we anticipate this reform will increase the ability of potential partners to work with the Labs by tailoring associated risk to specific circumstances.

The TCF, which is authorized in section 1001 of the Energy Policy Act of 2005, provides for funding from the applied energy programs to mature promising energy technologies with the potential for high impact. It leverages funding from the Department's applied energy research and development budget each fiscal year from the Office of Electricity, Office of Energy Efficiency and Renewable Energy, Office of Fossil Energy, Office of Nuclear Energy, and Office of Cybersecurity, Energy Security, and Emergency Response with matching funds from private sources to achieve two goals. First, it is designed to increase the number of energy technologies developed at the Labs that achieve commercial development and commercial impact. Second, the TCF enhances the Department's technology transitions system with a forward-looking and competitive approach to lab-industry partnerships.

Among the programs managed by OTT are two that improve availability of and streamline access to the expertise, facilities and technologies of the Labs. Energy I-Corps, modeled on the successful National Science Foundation's I-Corps program, trains Lab researchers to assess the commercial viability of their technology through an extensive engagement with private sector companies. The LPS serves as a single access point to the DOE Lab complex for investors, innovators and institutions allowing advanced, yet user-friendly search capabilities across numerous technology areas within the DOE portfolio. By enabling more streamlined access to

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: ***The Status and Outlook of Energy Innovation in the United States***
Questions for the Record Submitted to the Honorable Paul M. Dabbar

DOE expertise, information and capabilities, LPS catalyzes connections needed to combine technologies and form partnerships for collaboration with businesses and universities and allow maturing technologies to succeed.

DOE also conducts outreach to the private sector to increase awareness of the DOE's technical expertise and portfolio of technologies and facilitates private sector collaboration and partnerships with the Labs. Additionally, DOE has kicked off a new series of Summits called InnovationXLab. These Summits are designed to increase the engagement of the Labs with the private sector on high-impact, and potentially transformative, innovations and technologies.

Q3. There was significant discussion around the Department of Energy's Loan Programs Office at the hearing. With approximately $40 billion in remaining loan authority that could catalyze an additional $20-$40 billion of private capital, the Loan Programs Office seems like an obvious source of funding for spurring energy innovation.

Q3a. Why have there been no new loans made by the Loan Programs Office in the current administration?

A3a. Historically, the Loan Programs Office (LPO) has made loans and loan guarantees under four programs: Sec. 1703, Sec. 1705, the Advanced Technology Vehicles Manufacturing loan program, and the Tribal Energy loan guarantee program. LPO has only made loan guarantees to three borrowers under the Sec. 1703 program since it was authorized in 2005, all related to a single project, totaling approximately $12 billion. LPO's authority to guarantee loans under Sec. 1705, provided by the American Reinvestment and Recovery Act of 2009, expired in 2011. Since its inception in 2007, only five loans have been made under the Advanced Technology Vehicles Manufacturing loan program, none of which closed after 2011. LPO has provided no loans to date through the Tribal Energy program since it was first authorized in 2005. The Tribal Energy loan program did not receive appropriations from Congress until FY 2017.

The lack of recently closed loans to new borrowers in these programs is a function of their ineffectiveness at attracting borrowers who have viable projects, yet are unable to secure private sector financing. In addition, due to the complexity of LPO projects, financial close only occurs after developmental timelines significantly longer than projects financed by the private sector.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

For example, the Department of Energy first announced conditional commitments to the owners of Vogtle Units 3 and 4 in February 2010, but the loan guarantees to all three borrowers did not close until June 2015, and operations are not scheduled to commence until 2021.

The history of LPO's loan programs reinforces our experience that the Federal role in supporting advanced technologies is strongest in the early stages of research and development. The Government should not be in the business of picking which technologies "win" the commercialization race and displacing private sector investment opportunities.

Q3b. What is the Department of Energy doing to accelerate deployment of the $40 billion in remaining loan authority?

A3b. After receiving administrative appropriations in the FY19 Omnibus Appropriations Act, LPO continued to review applications submitted under currently open solicitations across the Title 17 Innovative Technology Loan Guarantee Program, Advanced Technology Vehicle Manufacturing Loan Program, and Tribal Energy Loan Guarantee Program. LPO will continue to work with applicants and conduct due diligence consistent with current law. The amount of time required for LPO to conduct due diligence and negotiate with applicants is largely dictated by the applicants' willingness and ability to provide sufficiently detailed information and assurances to enable LPO to appropriately assess credit risks, including the reasonable prospect of repayment.

Q3c. How many loans are expected to close in the next 12 months?

A3c. The recently released FY 2020 President's Budget assumes that $3.7 billion in conditionally committed loan guarantees for Vogtle Units 3&4 will reach financial close in FY 2019, and in fact the underlying loans successfully closed in March 2019, and are included in the figures in response to Q3a. Lake Charles Methanol (LCM) has an active conditional commitment for up to $2 billion in loan guarantees. While LPO continues to work with LCM, we are unable to provide a precise date for financial close.

The FY 2020 Budget carries forward the Administration's proposal to eliminate the loan programs. Given historical performance, it is unclear that any applicant currently seeking conditional commitment would reach financial close within 12 months. Currently, LPO is engaged with numerous projects at various stages along the project development continuum.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

QUESTION FROM SENATOR RON WYDEN

Q1. Given the inherent environmental toil, geopolitical uncertainties, and the growing public safety issues from lithium-ion battery fires in trash facilities, I was excited to hear that DOE is aiming to capture 90 percent of all lithium-based technologies in the United States. The Lithium-Ion Battery Recycling Prize and the establishment of an associated Battery Recycling R&D Center are important steps, but are there other actions legislators' can take to jumpstart lithium-ion disposal and recycling infrastructure to mitigate this risk?

A1. The U.S. Department of Energy (DOE) supports a proactive and comprehensive approach to addressing the challenges of using rare earth elements and other critical materials in energy technologies. The Department's strategy is three-fold: 1) diversifying global supply chains to mitigate supply risk; 2) developing material and technology substitutes; and 3) promoting recycling, reuse and more efficient use to significantly lower global demand for critical materials.

As research continues to lower cost, the global demand for lithium-ion batteries for a variety of applications, including consumer electronics, defense applications, grid storage, and electric vehicles, is expected to grow. Though this growth represents a great opportunity, it creates a potential supply chain constraint on the critical materials needed to produce lithium-ion batteries. Cobalt is of particular concern due to high domestic import reliance (72%) and geopolitical dynamics – 58% of the global cobalt supply comes from the Democratic Republic of Congo and more than 50% is refined in China. Cobalt chemical production is even more highly concentrated in China.

The Department's Office of Energy Efficiency and Renewable Energy, through its Advanced Manufacturing Office (AMO) and Vehicle Technologies Office (VTO), is working to address these issues. AMO focuses on elemental recovery and VTO focuses on recovery, recycling, and reuse of lithium-ion battery components and materials.

VTO has increased its focus on lithium-ion battery recycling to support environmental, economic, and supply chain reliability objectives. Through a reliable and self-sustaining recycling infrastructure, the United States can decrease its dependence on foreign sources to support the domestic lithium-ion battery industry. VTO's strategy is three-fold: research to reduce the amount of cobalt needed for next-generation batteries, increased focus on the economic recovery of lithium-ion batteries through the ReCell Center, and optimized collection of spent batteries through the Lithium-Ion Battery Recycling Prize. Together, this strategy has the long-term potential to supply over 60% of the material for next generation batteries.

The Critical Materials Institute, an energy innovation hub managed by AMO, has addressed critical materials, including lithium and cobalt, through research and development in four areas: diversifying supplies, developing substitute materials, reuse and recycling, and crosscutting research. Unconventional resources, including geothermal brines, are one avenue to diversify supplies; patent applications have been filed on extraction of lithium and separation of lithium-chloride from geothermal brines. Additionally, elemental extraction and new pathways (disassembly and remanufacturing) from electronic waste, including but not limited to lithium-ion batteries, are being investigated to advance reuse and recovery science and technology.

In the United States, certain batteries are subject to the Mercury-Containing and Rechargeable Battery Act (the Battery Act; P.L. 104-142). Others, like lead- acid batteries, must be managed as Universal Waste (40 CFR Part 273) and are recycled at nearly a 99% rate due to the economic value of the materials.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

QUESTION FROM SENATOR ANGUS S. KING, JR.

Q1. As Dr. Moniz mentioned in his testimony, more collaboration and cross-agency efforts on energy innovation developments are key to the US maximizing their RDD&D investments. One place where this seems to be happening to an extent is between the Department of Energy and the Department of Defense. Can you please provide as much detail as possible on the partnership and/or demonstration energy projects that the Department of Energy is working on in conjunction with various Department of Defense programs?

A1. The Department of Energy's (DOE) Office of Electricity (OE) is collaborating with the Department of Defense (DOD) and Department of Homeland Security on identifying critical infrastructure and restoration strategies for Defense Critical Electric Infrastructure (DCEI). Per section 215A of the Federal Power Act, as amended by section 61003 of the Fixing America's Surface Transportation Act of 2015 (Pub. L. No. 114-94), "[t]he term 'defense critical electric infrastructure' means any electric infrastructure located in any of the 48 contiguous States or the District of Columbia that serves a facility designated by the Secretary [of Energy] pursuant to subsection [215A(c), of the Federal Power Act], but is not owned or operated by the owner or operator of such facility." This definition is similar to the 2010 Grid Reliability and Infrastructure Defense Act, which also included Alaska, Hawaii, and the territories. OE has completed the first phase of the analysis, which identified paths of power flow to the identified defense facilities and evaluated these paths for resiliency and security.

OE is also in a partnership with DOD for the PowerPyramid and Battery Energy Storage System (BESS). The two-week test will demonstrate the system's ability to provide stable energy storage to a military base's electrical distribution circuit to enhance power surety in both islanded and grid-tied operation. The project is in partnership with the North American Aerospace Defense Command (NORAD) and its battery vendor, Erigo Technologies.

In addition, OE is collaborating with the U.S. Army Corps of Engineers' Engineer Research and Development Center and the Cold Regions Research and Engineering Laboratory to evaluate the potential of energy storage in arctic and sub-arctic military bases.

The DOE Office of Advanced Research Projects Agency-Energy (ARPA-E) is partnering with the DOD to test and demonstrate advanced energy technologies that have the potential to enhance the military's mission-readiness. For example:

- ARPA-E's AMPED program worked in parallel with DOD's Hybrid Energy Storage Module to develop storage technologies for all three services and safely pack more energy into batteries. A battery architecture and sensor developed as part of the AMPED program was used in the U.S. Navy's follow-on programs;

- ARPA-E is currently collaborating with the U.S. Navy to reduce the energy consumption of deployed cooling technologies, building off of the technologies developed as part of the agency's BEETIT program;

- ARPA-E regularly shares information with the U.S. Navy regarding its power electronics programs (e.g., CIRCUITS and BREAKERS) to assist in its transition to electric ships. U.S. Navy personnel also participate in program reviews in this technical area;

- The U.S. Army is in the process of testing a novel battery technology developed as part of ARPA-E's IONICS program that could prove safer than the flammable liquid electrolytes used in today's lithium-ion batteries;

- The Army Research Lab is using a generator developed as part of the GENSETS program to power an experimental small vehicle; and

- ARPA-E is developing a partnership program with DOD's Environmental Security Technology Certification Program (ESTCP) to demonstrate ARPA-E technologies at DOD installations, with an expected Memorandum of Agreement by month's end.

The Water Power Technologies Office (WPTO) within DOE's Office of Energy Efficiency and Renewable Energy (EERE) has also been collaborating with the DOD's Naval Facilities Engineering Command (NAVFAC) Engineering and Expeditionary Warfare Center (EXWC) for several years to support testing of next-generation wave energy technologies and instrumentation systems at the Navy's Wave Energy Test Site (WETS) off Marine Corps Base Hawaii at Kaneohe Bay on the island of Oahu in Hawaii. At least two other technology tests are planned for the coming two years for WPTO awardees at WETS.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Paul M. Dabbar

QUESTIONS FROM SENATOR JOHN HOEVEN

Q1. You mention in your testimony how costs to consumers, energy production, and emission rates have improved due to key partnerships between the Department of Energy (DOE) and the private sector as well as bipartisan support for federal research. The State of North Dakota and lignite coal industry are heavily invested in advancing solutions to continue to operate existing power plants and develop new technologies that allow us to be better stewards of our environment.

Q1. Does DOE remain committed to helping states and industry address and further carbon capture, utilization, and storage (CCUS) technologies?

A1. Yes. The Department of Energy's (DOE) carbon capture, utilization, and storage (CCUS) research and development (R&D) portfolio includes a broad range of stakeholders that include industry, academia, national laboratories, non-governmental organizations, and federal, state, and local government agencies. The Department is always available to assist stakeholders should they have questions about CCUS technologies or DOE's R&D programs.

Q. Perfecting carbon capture, utilization, and storage (CCUS) technology offers both domestic and international opportunity. Once the cost-effective systems are perfected, they can be deployed on existing power plants around the country and around the world.

In North Dakota, we are advancing "Project Tundra." By putting a CO2 capture retrofit onto the Milton R. Young Station, we will be able to use the CO2 to produce more oil in the Bakken and safely sequester the CO2. Project Tundra is a revolutionary showcase of CCUS technology that will prove that commercial cost-effective CCUS is environmentally beneficial, and economically viable. I believe that Congress should continue to incentivize the development and deployment of CCUS technology through the tax code, which is why I have been working to enact bipartisan reforms to existing tax credits, such as 45Q, and 48A, to foster the development of carbon capture technology.

Q2. Could you speak to the benefits of continued federal support for enabling the commercial application of carbon capture retrofits to extend the use of existing coal units?

A2. Retrofitting existing coal fired power plants with carbon capture technologies is important to demonstrating the commercial viability of carbon capture technologies. DOE has assessed the benefits of the tax credits and it is clear that they enable deployment of CCUS technologies for storage in oil fields, but projects have a brief period of time to realize these benefits. DOE is planning to issue a funding opportunity announcement in Q2 of FY 2019 to support two Front End Engineering and Design (FEED) studies for one carbon capture retrofit and for a second carbon capture system on a coal or natural gas plant. In addition, the Department continues to support three projects conducting carbon capture feasibility studies on three coal fired power plants: in North Dakota (at the site of project Tundra), Nebraska, and Indiana.

The Bipartisan Budget Act of 2018 substantially increased and extended the 45Q tax credit, in turn increasing the applicable value of carbon dioxide (CO_2) stored in geologic formations to $50 per ton, and the applicable value of both CO_2 used for enhanced oil recovery operations as well as CO_2 "utilized" and permanently removed from the atmosphere to $35 per ton. DOE stakeholders have expressed interest in using this tax credit to help finance CCUS projects, but they have also raised concern about the uncertainty regarding the requirements for construction to commence prior to January 1, 2024 will prevent qualified facilities from meeting the statutory deadline required by recipients of the 45Q tax credit will prevent qualified facilities from meeting the statutory deadline for construction to commence prior to January 1, 2024. In response to those concerns, DOE is prepared to work with the Treasury Department as outlined in a December 13, 2018 memo from Secretary Perry to Secretary Mnuchin: https://www.energy.gov/sites/prod/files/2019/02/f59/Letter%20from%20Secretary%20Perry%20-%2045Q.pdf

Q3. The Energy and Environmental Research Center (EERC) at the University of North Dakota (UND) has an ongoing cooperative agreement funded through the Energy Department's Office of Fossil Energy and administered by the National Energy Technology Laboratory (NETL).

The EERC leads the Plains CO2 Reduction (PCOR) Partnership, a collaboration of more than 80 U.S. and Canadian stakeholders that are working to take CCS out of the lab and into the field. EERC secures a minimum overall 20 percent cost share from nonfederal partners.

Q3. Will you work with us to continue and further these important cooperative agreements with the Department?

A3. Yes. In FY 2019, DOE renewed its cooperative agreement with the University of North Dakota's Energy and Environment Research Center (EERC) for fossil energy research, and will release a funding opportunity announcement in the second quarter of FY2019 to competitively select projects that will continue the Regional Partnership initiative. We welcome the opportunity to work with Congress on ensuring that the Regional Partnerships continue to utilize their expertise, knowledge, and stakeholder relationships to advance commercial-scale CCUS deployment in the U.S.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: ***The Status and Outlook of Energy Innovation in the United States***
Questions for the Record Submitted to the Honorable Ernest J. Moniz

Questions from Chairman Lisa Murkowski

Question 1: Over the past several years, the Department of Energy has made great strides in coordinating research efforts and encouraging inter-office collaboration. In order to get the greatest use from the taxpayer dollar, what can be done within DOE and across the government to make the most efficient use of resources to accelerate innovation for high priority clean energy technology research?

Answer 1: In the Energy Futures Initiative (EFI) report, co-authored with IHS Markit, *Advancing the Landscape of Clean Energy Innovation*, Chapter 4 focuses on the role of the federal government and we included the following recommendations regarding the role of the federal government in the energy innovation ecosystem. I strongly believe these steps are necessary to achieve the goals set forth in your question:

- The critical collaboration between public and private sector players would be strengthened by several adjustments to the current scope and administration of federal clean energy activities. Private sector commitments to develop and adopt new clean technologies draw heavily on the foundational scientific insights and risk mitigation provided by federal energy innovation programs.
- Establishment of a reliable source of DOE R&D funding. This step would facilitate planning on the part of universities, labs, and the private sector, and permit researchers and entrepreneurs to commit to the multi-year undertakings needed for advances in clean energy. Dedicated sources of federal R&D funding should be evaluated. These can be employed to more directly engage industry to ensure alignment of policies, programs, and players.
- A long-term increase in such funding to the levels recommended in previous studies based on international and cross-industry benchmarks — approximately twice today's level. This increase would accelerate economy-wide engagement in clean energy invention and development.
- Expansion of DOE loan programs to support late-stage demonstration and early deployment of clean energy innovations by the private sector. The program could leverage $100 billion of incremental energy investment without requiring new appropriations.
- Implementation of administrative and legislative reforms to increase the impact of the department's R&D programs. These reforms include:
  - ◊ Organizational and budgeting alignment around critical energy applications and highest priority opportunities, to reflect the need for systems-level integration and to avoid gaps in programs that span multiple fuels.
  - ◊ A multi-year and multi-agency portfolio planning process with broad-based stakeholder involvement.
  - ◊ Greater use of flexible financial vehicles like Technology Investment Agreements and prize competitions to simplify public-private partnerships.
  - ◊ Strengthened management of demonstration projects through stage-gated project management, risk-based cost sharing, and assignment of demonstration project oversight to a single office.
  - ◊ Clearer performance standards at each stage of the innovation process to assist potential investors in evaluating risk.
  - ◊ Systemic assessment of clean energy innovation progress and the impact of Federal programs.

Question 2: In the executive summary of your report, "Advancing the Landscape of Clean Energy Innovation," cities are mentioned as "crucial clean energy innovation testbeds" as we implement smarter,

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

urban technologies. How do our rural communities fit in to this innovation testbed picture? We visited Oscarville, Alaska, together - there are only a handful of people living there, and certainly no grid or smart energy technology, but a need for a cleaner more reliable energy source. Is there a role for those kinds of communities, though, in driving clean energy technology innovation?

Answer 2: There is no question that there is an important role for every community in driving clean energy technology innovation; however, that role will vary based on a community's needs and the level of public and private investment in physical and human infrastructure.

In particular, *Transforming the Nation's Electricity System: The Second Installment of the Quadrennial Energy Review* (QER 1.2) noted that:

- Tribal lands have the highest rates of unelectrified homes in the contiguous United States and Alaska. The extreme rurality of some tribal communities, coupled with high levels of poverty, presents an economic challenge for the electric utilities trying to serve them.
- Insufficient broadband access in rural areas could inhibit the deployment of grid-modernization technologies and the economic value that these technologies can create.

This is why QER 1.2 identified and addressed the needs of rural communities in a number of its recommendations. These recommendations included:

- Provide funding assistance to enhance analytical capabilities in state public utility commissions (PUCs) and improve access to training and expertise for small rural electric cooperative and public power utilities.
- Provide assistance to address rural, islanded, and tribal community electricity needs.
- Support the achievement of full tribal land electrification.
- Leverage utility broadband build-out to expand public broadband access in rural areas.

As you mention, the need for a cleaner, more reliable energy source is critical in many rural communities for quality of life and also take advantage of opportunities afforded by broadband. According to the Federal Communications Commission, of the approximately 25 million Americans without access to broadband, 19 million live in rural communities. The evidence is clear: closing the digital divide can accelerate clean energy innovation.

Rural communities are already demonstrating a capacity for energy innovation. For example, as mentioned in the QER 1.2, co-ops have installed the greatest percentage of advanced metering infrastructure (AMI), with 51 percent penetration, compared to 41 percent for IOUs and 26 percent of publicly owned utilities. Rural electric co-ops can more easily adopt energy efficiency or renewable energy programs tailored to their members. Some rural co-ops are adding biodigesters to convert solid waste from dairy cows to electricity, smart electric water heaters to store wind energy, improved forecasting for solar and wind energy, and other DR technologies that take advantage of resources in rural areas. Many of these DR and storage technologies could be expanded with improved telecommunications access.

Another example of rural energy innovation that is highlighted in the QER 1.2 leverages the RUS program which partners with cooperatives to finance improvements in rural communities, many of which

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

are low- income. Roanoke Electric Cooperative implemented a program to make investments tied to each meter that are funded by an RUS loan. The co-op paid for the installation of improved insulation, duct and air sealing, heat and water pump upgrades, and efficient lighting. The co-op recovers its efficiency investment through a tariff on the bill from co-op members, who still see savings on their bill from the reduced electricity use. After efficiency upgrades, the average savings was $120, which the member and the co-op would split; an average member would save $60 per month on his or her bill, and the co-op would pay off the efficiency upgrade in 10 years. Improvements to RUS loan programs, many of which are undersubscribed because of the programs' complexity or the inability to refinance to lower interest rates, could accelerate the development of renewable energy and energy efficiency projects in rural areas.

Question 3: I believe that microgrids offer an enormous opportunity for increasing the deployment of various clean energy technologies – from micro-reactors and marine hydrokinetics to wind and solar. The Department should increase efforts in this area to conduct more microgrid systems research that will de-risk microgrid technologies and emerging micro-generation options. It should build off the great work of the Grid Modernization Lab Consortium to take advantage of the early deployment opportunities that exist in today's operating microgrids, like the many in my home state of Alaska.

a. What do you believe is the value proposition for microgrids in accelerating our clean energy future?

b. Should the Department conduct an amped-up crosscutting microgrid research program to take advantage of these opportunities?

Answer 3 (a): As the Brooklyn microgrid project and, of course, the more than 200 microgrid projects in Alaska demonstrate, this technology is more than an alternative to traditional grid infrastructure. Microgrid technology is a platform for approaches to infrastructure constraints, the need for smaller loads, and renewable alternatives to the use of distillate fuel oil. The 21st century electricity system will rely on a number of advanced technologies for reliable, affordable, secure, and clean energy. Microgrids with their resiliency and multiple applications will be and should be a key technology.

Answer 3 (b): Absolutely. This is why one of the first near term actions recommended in EFI's report, co-authored with IHS Markit, *Advancing the Landscape of Clean Energy Innovation*, that "Congress and the Administration should initiate efforts to reorganize the Federal energy RDD&D portfolio and the Department of Energy toward a fuel- and technology-neutral structure that (1) aligns with the highest priority opportunities, (2) enables systems-level integration, and (3) avoids gaps in crosscutting programs."

Question 4: There is no question in my mind that advanced nuclear should be part of any energy solution. One reason for this is the tremendous amount of emission free energy that they can provide. Leading on advanced nuclear will also reassert our role on the world stage in developing non-proliferation policies and ensure a viable nuclear workforce here at home. How do you see advanced nuclear fitting into the clean energy mix both here in the United States and around the world?

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

Answer 4: We will need nuclear power – existing and new – in order to meet our national and global midcentury clean energy and climate goals. Nuclear power currently provides over 10 percent of the world's electricity, 18 percent of electricity in OECD countries, and 20 percent in the US. A November 2018 report by FTI-Compass Lexecon Energy Consultant, commissioned by Foratom, concluded that nuclear power must account for 25 percent of the EU's energy mix if the region is to meet its 2050 emission targets. And in EFI's report, co-authored with IHS Markit, *Advancing the Landscape of Clean Energy Innovation*, we identified advanced nuclear reactors, including SMRs, advanced reactors (large and small) for heat and power, and Generation IV reactors, among the critical subset of those technologies with a very high breakthrough potential in the report.

Question 5: Swedish mining company LKAB and its Norwegian partner are developing a carbon dioxide-free process for steel production and mining. Iceland has a "no waste" mantra, including a carbon recycling plant that turns carbon dioxide from a nearby geothermal power plant into methanol for vehicle fuel. There is a lot of energy innovation happening in the Arctic, often by necessity. Is the United States doing anything similar to these types of activities, and are there other areas where we could be learning from our international partners?

Answer 5: In 2016, Swedish-Finnish steel company SSAB, mining company LKAB, and power company Vattenfall launched an initiative to develop a steel production process that emits water rather than carbon dioxide, known as the Hydrogen Breakthrough Ironmaking Technology (HYBRIT) project. The HYBRIT project has a 20 year timeline: pre-feasibility study from 2016-2017, feasibility study-pilot plant trials from 2018-2024, and demonstration plant trials from 2025-2035. While promising, this is a very long timeline. I would also note that Vattenfall is also working with Cementa on a study of electrification of cement production. These initiatives are critical, as the industrial sector is not only one of the most difficult to decarbonize, it is also a major source of GHG emissions in the US.

The US has a number of options for reducing emissions from the industrial sector today, while also exploring options for deeper reductions in the post 2030 timeframe. These include fuel switching (to electricity or hydrogen), CCUS, CHP, and RNG. I would also note that the policy environment in these countries differ from that of the US. For example, Sweden's Climate Act binds the country to reach net-zero GHG emissions by 2045, and Finland's National Climate Change Act and National Energy and Climate Strategy establish a GHG reduction target from 1990 of at least 80 percent by 2050 and specifies key objectives and policy outlines through 2030. In comparison, currently the US is the only other nation, besides Syria which has been experiencing a civil war for the past seven years, which are outside the Paris Agreement.

Question 6: During the recent Arctic Frontiers Conference held in Norway, a Swedish Arctic energy company CEO announced a major project developing zero-carbon mining. He anticipates mining and tunnel operations being carbon-free in the next five to ten years at a specific site. Mining is certainly a challenging sector from an emissions perspective. Are there technologies being investigated in the U.S. that could lower carbon emissions from mining operations?

Answer 6: Yes. For example, in 2018 EFI initiated a Sustainable Mining Project to minimize the energy and environmental footprint of mining operations while preserving jobs and economic viability of these

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

operations. This pilot project involves working with mining companies, energy producers and policy organizations, organized labor, environmental non profits, state agencies, local communities and Nativa American tribal governments.

Question 7: What are the most promising developments in carbon capture, utilization, and sequestration innovation and can you tell me more about the role these technologies will play in the future? Furthermore, in order to get the Department of Energy set up for success in developing these technologies, what policy changes would you suggest?

Answer 7: Innovation in and implementation of CCUS is critical to our collective deep decarbonization success. Coupled with the challenges associated with decarbonization of the industrial sector, CCUS has added critical importance. There are a number of promising developments in CCUS innovation. For example, excerpting from EFI's May 2018 report, *Advancing Large Scale Carbon Management: Expansion of the 45Q Tax Credit:*

> The Bipartisan Budget Act (BBA) passed by Congress on February 8, 2018 included expanded provisions for carbon dioxide (CO2) capture, utilization, and storage (CCUS). These provisions, based on Senate Bill S. 1535 (FUTURE Act) and its companion legislation in the House, expand and reform the Section 45Q tax credits originally enacted in 2008. They include an increase in the credit value for qualifying projects, a longer time horizon for developers to claim the credit, a more expansive definition of qualifying utilization projects beyond enhanced oil recovery (EOR), and eligibility of direct air capture. The provisions act like a production tax credit and are designed to encourage innovation in and adoption of low-carbon technologies related to CCUS, including direct air capture (DAC) of CO2 and conversion of CO2 into useable products.
>
> The new 45Q provisions have the potential to significantly enhance the development and market diffusion of CCUS technologies and processes in both industrial and power applications, creating commercial opportunities both in the U.S. and abroad. The provisions provide greater market and financing certainty to help attract additional follow-on investment from the private sector. They will also likely help accelerate the pace of innovation in CCUS technologies and processes, and could mitigate asset risk for fossil fuel producers by enabling continued use of fossil fuels in a carbon-constrained world.
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> While the 45Q provisions represent a major step forward for emissions reductions, the size and duration of the credits may be insufficient to incentivize retrofits for the variety of facilities that are eligible, including many coal and natural gas plants. Also, the long-term post-injection monitoring, reporting and verification requirements could become an impediment for some operators, possibly limiting the universe of those that might otherwise take advantage of the credits.
>
> To address these and other issues, a more comprehensive policy framework may be needed to maximize the value of the credits. Nonetheless, the new provisions are a critical step forward and will enable substantial emissions reductions for many facilities, especially industrial sites. Given the short time to begin construction on projects, developers, states, and investors must act

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

expeditiously to maximize the commercial and financial opportunities enabled by the expanded 45Q provisions and thereby kick-start larger scale deployment of CCUS.

Question 8: As we consider ways to encourage more U.S. investment in energy technology innovation, how do you view the potential roles for technologies like off-shore wind and marine renewable energy sources like wave and tidal?

Answer 8: I am a longstanding proponent of an "all-of-the-above" energy strategy accompanied by a commitment to low carbon, including advancing and engaging in cost reduction for CCUS. We need to be technology neutral and focus on attributes (such as clean, secure, affordable, and able to provide electricity access for a range of locations and population size) and focus on development of near, intermediate and long term technology development. We will need a wide range of clean technologies to fuel the US economy and international competitiveness in a decarbonized world. In EFI's report, co-authored with IHS Markit, *Advancing the Landscape of Clean Energy Innovation*, we recognized the promise of water power (hydro and marine hydrokinetic) in a clean-energy future and identified innovation opportunities, specifically: marine hydrokinetic component technology, supporting research, monitoring and modeling hydro systems in the near term (2025), and materials and turbine designs and modularization in the intermediate term (2035). Similarly for offshore wind, we identified demonstration projects to test alternative concepts (e.g., tethering), applications (icing conditions), and cost reduction opportunities for the near term, and deep water offshore wind platforms for the intermediate term.

Question 9: Micro-reactors have the potential to lower the cost of electricity, increase reliability and resilience, and decrease emissions for many challenging applications. These advanced reactors would compete with the diesel generator market and could transform life for remote communities, provide stability to military installations, and even make mining or mineral development operations economically viable.

a. What is the potential for these promising micro-reactors?

b. What are your chief policy concerns relating to getting these micro-reactors to market?

Answer 9: In EFI's report, co-authored by IHS Markit, *Advancing the Landscape of Clean Energy Innovation*, we included advanced nuclear reactors on the breakthrough technology shortlist, which includes small modular reactors (SMRs), recognizing that SMRs can change financial and application dynamics, and research and design advancements for SMRs are improving safety, proliferation, security, and environmental concerns. I would also note that EFI recently attended a technical workshop hosted by the International Energy Agency on the role of nuclear power in a clean energy system where significant discussion addressed the role of micro reactors as potential game changers for remote, rural and small communities (including off grid application), as well as promising prospects for increasing operational flexibility (for example to balance variable renewable generation), and financial competitiveness. Chief policy concerns are not related specifically to this technology, but instead relate to the overall US framework for clean energy innovation at the federal level.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

Question 10: I understand that today's technologies are finding economic applications on the grid and in electric vehicles. We have heard at previous hearings about the limitations of today's technologies and the importance of developing next-generation storage.

a. What are the most promising energy storage technologies under development today?

b. How could efforts be accelerated for these important technologies?

Answer 10: Based on technical merit, market viability, compatibility, and consumer value, in our report, co-authored with IHS Markit, *Advancing the Landscape of Clean Energy Innovation*, we identified storage and battery technologies as on the short list of technologies with high breakthrough potential. We recognized that, "Storage, including batteries, can be used to address many challenges facing the power sector today, including integrating variable fuel sources into the grid, deferring capital investment in infrastructure, and improving economic dispatch, efficiency, and power quality." The challenge is the necessity for huge scale up in the face of supply chain issues associated with lithium and other energetic materials, battery manufacture, charge rate, energy density and cost. Chapter 3 provides a useful discussion:

> Storage, including batteries, can be used to address many challenges facing the power sector today, including integrating variable fuel sources into the grid, deferring capital investment in infrastructure, and improving economic dispatch,efficiency, and power quality. Batteries can also support transmission system balancing and coordination of distributed energy resources on distribution networks. In addition, they can be positioned in local communities or behind the customer meter to contribute to emergency preparedness and resiliency and can be used to reduce peak demand and reduce demand charges. Deployment of these technologies — along with other innovative solutions, including advanced control software — can enhance the grid's capabilities and flexibility.
>
> Lithium-ion systems dominate the current deployment landscape for grid-scale electric energy storage in the United States and demand is expected to grow. According to Lazard, lithium-ion systems provide an economical battery storage solution across multiple power sector use-cases, including peaker replacement and commercial behind-the-meter supply. This is mainly due to falling costs of lithium cells and modules and increasing battery performance in terms of charging efficiency and power quality.
>
> This technology has potential for cost reductions due to emerging energy storage mandates and a burgeoning manufacturing capacity. There are many different lithium-ion chemistries that can be leveraged for grid-scale applications, each with differing power-versus-energy characteristics. Lithium-sulfur chemistries offer the potential for even greater energy densities than lithium-ion batteries.
> Various technology configurations exist, with some using nanomaterials and nanostructures that show enhanced results (e.g., higher energy density) compared to conventional batteries.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

As lithium and battery storage grows in strategic importance to power generation, transportation, and digitalization, supply chains must be carefully analyzed. Rapid increases in demand for lithium for a range of batteries for electric grids, phones, computers, vehicles could stress the supply chain. The number of electric vehicles globally, for example, could grow from 2 million in 2016 by 9 to 20 million by 2020. The growth of the global Internet of Things may nearly triple by 2020. Major investments by an industry innovator, Tesla, and a major U.S. competitor, China — with 2021 targets of 35 gigawatt-hours (GWh) and 120 GWh, respectively — would carry global capacity to 270 GWh, enough for 30 million Prius type PHEVs (at 5-35 kilowatt-hours, or kWh, per vehicle), or about 3 million Tesla S class vehicles (at 80 kWh and more per vehicle). A global fleet of 4 million EVs of all types would require approximately 100,000 metric tons (MT) of lithium per year.

The electricity grid is another sector where demand for battery storage could be significant. According to the Energy Information Administration (EIA), the electric power industry has installed roughly 700 megawatts (MW) of utility-scale batteries on the U.S. electric grid — mostly in the last three years. As of October 2017, these batteries made up about 0.06 percent of U.S. utility-scale generating capacity. Another 22 MW of batteries were planned for the last two months of 2017, with 69 MW more planned for 2018.

Barriers to the implementation of batteries on the grid fit into five general categories: modeling, technological, financial, market, and regulatory. These all center around the lack of knowledge and experience of utilities and regulatory bodies in the utilization of — and capturing the many values of — batteries. A combination of RDD&D on batteries, as well as adoption campaigns by the utilities and public utility commissions, is needed to take advantage of the value of batteries throughout the grid.

Several chemistry options "beyond lithium-ion" are being explored, such as lithium-sulfur, lithium-air, sodium, magnesium, and redox-flow chemistries. Each comes with benefits and challenges. Sodium-sulfur (NaS) batteries, for example, are a commercial technology with applications in distribution grid support, wind power integration, and other high-value grid services. U.S. utilities
have installed about 9 MW of NaS batteries for peak shaving and firming wind installations, and have plans to install another 9 MW. NaS batteries have significant potential for broader use on the grid because of their long discharge times, their relatively high round-trip efficiencies, and their ability to quickly respond to control signals for regulation or improving power quality. However, NaS batteries use hazardous materials, including metallic sodium, which is combustible if exposed to water. Research needs include advances in chemistries, materials, and designs to reduce operating temperatures and improve safety features.

<u>Question 11</u>: We have heard many predictions about the adoption of electric vehicles. Many experts believe that these vehicles and in some cases hydrogen fuel cell-powered transportation could lead to a decrease in emissions from vehicles on our roads. At the same time, some innovators are pursuing advanced biofuels for difficult transportation subsectors like aviation.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

What do you think the timeline is for these changes in the transportation sector to be widely adopted and make an impact on global emissions?

Answer 11: We identified hydrogen as a clean energy carrier, storage medium and enabler of decarbonized industrial and transportation sectors. There are numerous applications for hydrogen in a low carbon environment including transportation, manufacturing and electric power and a number of these applications are or will be available in the near (2025) and intermediate term (2035); however, many of the challenges are associated with infrastructure, the development of which is a longer term challenge (2050).

Questions from Ranking Member Joe Manchin III

Question 1: According to the International Energy Agency (IEA), in 2017, the U.S. used coal for 31% of its electricity, and that number is forecast to continue to decline. In China, coal comprised 67% of the electricity mix, and 74% in India. While Asian countries are taking some steps to reduce carbon emissions, the IEA says coal will still comprise about 51% of the electricity mix in China, and 57% in India in 2040. I believe that we need to economically incentivize the world to use cleaner energy and to create a workforce in America that manufactures the next generation of energy technology.

Is the U.S. currently in a position to lead the world in developing the next generation of clean coal technologies? If not, why not?

Answer 1: The U.S. is well-positioned to lead the world in developing the next generation of clean coal technologies, in part due to the Carbon Capture Program at DOE's National Energy Technology Laboratory, but there are additional steps that could and should be taken. In our report, co-authored with IHS Markit, *Advancing the Landscape of Clean Energy Innovation*, we noted that:

> CCUS has been challenging to deploy at commercial scale. The U.S. currently has nine large-scale integrated CCUS projects (defined as having the capacity to capture upwards of 500,000 metric tons of CO2 per year and combining both capture and storage capabilities). Three of these projects began operation in the 1970s and '80s; the remainder began operation between 2010 and the present. Apart from a 2017 retrofit of Archer Daniels Midland's Illinois ethanol refinery, which stores captured CO2 in an underground saline aquifer, all of the currently operating projects rely on the economics of EOR. Total capture and storage capacity from these projects amounts to 22 million metric tons of CO2, a minuscule percentage of the approximately 5 billion metric tons of CO2 emitted annually in the United States.
>
> Among the large power plant CCUS projects undertaken over the past decade Petra Nova's success in achieving operational status is the exception; most have found it difficult even with federal support to attract long-term financing under the weight of cost, legal challenges, and regulation. The problem of cost may be ameliorated by recent increases in tax incentives. "45Q" federal tax credits for carbon capture have been increased substantially, from $20 per Mt for secure geological storage and $10 per Mt for EOR, to $50 and $35 respectively.

> Another challenge to CCUS deployment in the U.S. is the lack of midstream infrastructure capacity. In order to connect power plants and other CO2 sources east of the Mississippi River to potential storage and EOR sites in the Midwest, it's estimated that 10,000 to 30,000 miles of CO2 pipeline would need to be added to the 5,000 miles currently available. Further difficulties are presented by federal standards for wells, which are far more stringent for geological sequestration than for EOR.88

And, as we further recognized in *Advancing the Landscape of Clean Energy Innovation*, the new 45Q provisions also "have the potential to significantly enhance the development of market diffusion of CCUS technologies and processes in both industrial and power applications, creating commercial opportunities both in the U.S. and abroad. The provisions provide greater market and financing certainty to help attract additional follow-on investment from the private sector." We also, however, recommend that Congress "consider additional measures to facilitate and accelerate CCUS deployment, including addressing uncertainties regarding long-term post-injectin carbon manamgnet, monitoring, reporting and verification."

Question 2: I'm interested in how we can make the electric grid more efficient. High-voltage transmission lines are more efficient than distribution lines, but we still have losses of 8 to 15%. We all understand that making upgrades to the existing power grid is going to be expensive, but while we're talking about modernizing the grid, shouldn't we talk about what advanced materials can reduce electricity losses from the generating station to the customer? I understand ceramic materials may be promising but cost-prohibitive. I also understand that some magnesium compounds being tested in Europe may hold promise.

a. Is this an area that we should be prioritizing in our R&D funding?

b. What advanced materials can help avoid voltage drop?

c. Where are these technologies in terms of commercialization?

Answer 2: Advanced materials and nanotechnology are a critical research area with enormous potential for improving the energy system, including grid efficiency. In the *Quadrennial Technology Review: An Assessment of Energy Technologies and Research Opportunities* (September 2015), DOE identified transmission and distribution components among RDD&D opportunities, specifically:

- Material innovations for high-power, high-frequency, and high-reliability grid applications, including wide bandgap semiconductors
- Component designs, topologies, and systems based on solid-state devices that lead to higher performance, increased reliability, resilience, and lower costs

Question 3: According to the Department of Energy, 40% of the nation's energy is consumed in buildings. Energy efficiency improvements in the nation's building stock represent a tremendous energy resource if we can effectively access it.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

a. As you know, the Department of Energy has an entire program dedicated to energy efficiency in buildings. What are the most promising technologies or programs that DOE invested in to help make buildings more efficient?

b. What barriers are slowing us down on greater adoption of efficiency technologies in buildings?

__Answer 3__: As we note in our report, co-authored with IHS Markit:

> The buildings sector accounts for about 76 percent of electricity use and 40 percent of U.S. primary energy use and associated GHG emissions. Reducing energy consumption for buildings is essential for meeting national energy and environmental challenges and reducing energy costs for residences, commercial enterprises, building owners and tenants.

We further note, that, despite the challenge represented by the very large legacy buildng fleet:

> Opportunities for improved building efficiency are enormous. By 2030, building energy use could be cut more than 20 percent using technologies known to be cost effective today; emerging technology advances could cut energy use for buildings by more than 35 percent. Much higher savings are technically possible.
>
> Building efficiency involves the performance of a complex system designed to provide occupants with a comfortable, safe, and attractive living and working environment. It requires integrating architecture and engineering designs, construction practices, and intelligent operation of the structures into the larger grid and energy ecosystem. Through advanced sensors and controls and integrated grid operational models, buildings can be key demand-side management elements for optimizing grid efficiency — and the core of a Smart Cities architecture.
>
> The major components of energy consumption in buildings, and the fraction of total building energy they represent are:
> - heating, ventilation, and air conditioning — 35 percent;
> - lighting — 11 percent;
> - major appliances (i.e.,waterheaters, refrigerators, freezers,and dryers)—18 percent.
>
> The remaining 36 percent of building energy goes to a variety of other uses, including electronics. In each case, there are opportunities both for improving the performance of system components (e.g., improving the efficiency of lighting devices) and for improving the way they are controlled as a part of integrated building systems (e.g., sensors that adjust light levels to occupancy and daylight).
>
> Due to the long lifetime of the building stock, there needs to be a focus on retrofitting existing buildings. Efficiency improvements from retrofits can markedly change the environmental profile of buildings, especially when combined with the subsequent use of decarbonized electricity. Key research opportunities, many of which the DOE has invested in, include the following:

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

- High-efficiency heat pumps that reduce or eliminate the use of refrigerants with Global Warming Potential, if they were to leak to the atmosphere;
- Thin insulating materials;
- Windows and building surfaces with tunable optical properties;
- High-efficiency lighting devices, including improved green light-emitting diodes, phosphors, and quantum dots;
- Improved software for optimizing building design and operation;
- Low-cost, easy to install, energy harvesting sensors and controls;
- Interoperable building communication systems and optimized control strategies; and
- Decision science related to issues affecting purchasing and operating choices

Question 4: Department of Energy estimates that 1.5 million new energy jobs will need to be filled by 2030, 200,000 of which will need STEM skills. This demand comes at a time when out our energy workforce is aging, with 40% of all transmission and distribution workers eligible to retire in the next several years. Meanwhile, over 70% of energy employers reported difficulty hiring qualified workers within the last year. It is critical that the Department of Energy take a leadership role in establishing training programs to close this skills gap. But we must ensure that any and all training programs target and recruit from groups that are often neglected, like women and veterans, as well as communities like those in West Virginia where the downturn in coal has meant that people just being left behind.

What should DOE do to ensure that West Virginia's workers are not left behind as Congress works toward more comprehensive energy workforce training programs at DOE?

Answer 4: Together with the National Association of State Energy Officials, EFI launched the *2019 U.S. Energy and Employment Report* on March 6, 2019. The launch included a panel discussion of The 21st Century Workforce: An Emerging Crisis or Economic Opportunity, which identified the importance of trade apprenticeship programs, where a worker is paid while learning, early outreach at the high school level (at least), and an improved appreciation that construction is a high skill area of employment. With respect to improving employment of women and veterans, the panel noted the importance of both committed company leadership and program directors. Also, of note:

- Many of the energy job sectors are now racially more diverse than the U.S. workforce as a whole (22%).
  - 10-19% Latino or Hispanic compared to 17% overall.
  - 5-9% Black or African-American compared to 12% overall.
  - 7-10% 2 or more races compared to 2% overall.
  - EPG is the most diverse sector with 31% of the workforce people of color.
- Women make up from 23-32% of these sectors compared to 47% of the overall workforce.
  - Electric Power Generation employs the highest percentage of women.
- Veterans comprise about 9-11% of employees, compared to 6% nationally.
- Unionization rates are generally higher than the national rate of 6.5% in the private sector, ranging from 3-16%.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

Specifically with respect to workers and communities facing challenges due to the transitioning energy sector, the report, *Transforming the Nation's Electricity System: The Second Installment of the Quadrennial Energy Review* included several recommendations. For example in the section entitled, Meet Federal Commitments to Communities Affected by the Transformation of the Electricity Sector, the report stated:

> To achieve the transition to the electricity sector of the 21st century smoothly, quickly, and fairly, the Federal Government should offer a synthesized package of incentives that address the needs of the most important stakeholders both within and outside the electricity sector. Many of these needs are addressed through other recommendations on this list, including incentives to reduce the cost of flexible and clean assets, encourage the deployment of new and improved technologies throughout the electricity supply chain, and train workers for 21st-century electricity jobs. Recognizing that the shift to the 21st-century electricity system can impact communities that depend on 20th-century resources, the following recommendations provide transition assistance for communities affected by the multi-decadal decline in coal production.
>
> Recommendation 69. Fulfill Federal commitment to fund coal miner retiree benefits. Over the last 50 years, coal miners have repeatedly foregone increases in wages in exchange for pension and healthcare benefits. These benefits are now imperiled by (1) the recent bankruptcy of three of the largest public coal companies in America—allowing those companies to avoid fully funding their employees' benefit funds—and (2) the declining ratio of active contributing workers relative to beneficiaries in the health and pension funds. Recognizing the commitments to support coal miner retirement benefits made by the Federal Government in the 1946 Krug-Lewis Agreement, the 1992 Coal Industry Retiree Health Benefit Act, and the 2006 amendments to that act, and also recognizing the contribution that coal miners have made to the U.S. economy, the Administration strongly supports legislation that would transfer funds to the largest multi-employer health and pension fund serving retired coal miners and their families, thereby ensuring that it can continue paying benefits.
>
> Recommendation 70. Meet the Federal commitment to appropriate sufficient funding to accomplish the mission of the Abandoned Mine Lands (AML) Fund. DOI's Office of Surface Mining Reclamation and Enforcement estimates that there are more than $4 billion worth of high-priority, health- and safety-related, abandoned coal mine lands in the United States. At the same time, the AML Fund has an unspent balance of $2.5 billion dedicated to reclaiming these sites. The AML fees should be returned to their original 1977 levels to raise additional reclamation funds, and disbursements from the AML Fund should be accelerated over the next 5 years, enhancing economic development in distressed coal communities through reclamation employment.

In addition, the report recommended leveraging utility broadband build-out to expand broadband access in rural areas, noting:

> Broadband expansion into these regions would significantly advance grid modernization goals, while providing significant communications, connectivity, and educational benefits to numerous

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

regions of the country. Supporting broadband access in sparsely populated rural areas, many of which are low-income areas, is not, however, profitable for the private sector. Federal support would help enhance security, environmental, and economic development goals.

Question 5: The Department of Energy, since its creation, has played a critical role in supporting promising technologies through loan programs, national laboratory resources, pilot programs, and public-private partnerships. The formula for advanced nuclear has been no different but I believe there is room for improvement for strengthening and diversifying public-private partnerships. Leaders like Bill Gates and others in the advanced nuclear space are willing to put their money where their mouth is. I think the federal government should harness that interest while ensuring the taxpayer dollar is protected. Advanced nuclear has the potential to bring resiliency to the grid and, more importantly, is perhaps the only non-carbon technology for industrial heat applications.

a. How can the Department of Energy better facilitate its partnerships with advanced nuclear companies?

b. Process heat for industry is provided by fossil fuels, and in the U.S., represents 20% of energy-related CO_2 emissions. What is the DOE doing on ways that nuclear technologies can be partner technologies for industrial heat processes?

Answer 5: On page 160 of the EFI report, co-authored with IHS Markit, *Advancing the Landscape of Clean Energy Innovation*, we illustrate the volatility of funding for select DOE programs and nuclear energy program has the most extreme volatility. This lends more urgency to the importance of our broader recommendations for the federal government:

- Congress and the Administration should initiate efforts to reorganize the Federal energy RDD&D portfolio and the Department of Energy toward a fuel- and technology-neutral structure that (1) aligns with the highest priority opportunities, (2) enables systems-level integration, and (3) avoids gaps in crosscutting programs.
- Congress and the Administration should consider dedicated funding sources for energy innovation as a means to ensure predictable and increasing levels of clean energy RDD&D funding based on international and cross-sectoral benchmarks.
- Federal policymakers should expand demonstration projects for key breakthrough technologies, while ensuring accountability via stage- gated project management, risk-based cost sharing, and assignment of demonstration project oversight to a single office within DOE.
- DOE and other agencies, as appropriate, should increase collaboration with the private sector and academia, including:
  - Instituting a multi-year and multi-agency portfolio planning process with broad-based stakeholder involvement from the private sector and academia.
  - Expanding use of prize authority to foster competition and open innovation.
  - Simplifying public-private partnerships with flexible financial vehicles like Technology Investment Agreements.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Ernest J. Moniz

Question 6: The latest National Climate Assessment warns that the worst effects of climate change could be felt sooner than we thought and that we must act in meaningful ways sooner. In terms of progress towards a low-carbon economy, what do you think is achievable in the next 10 years?

Answer 6: We can make meaningful progress by 2030 in two important ways. First, we can achieve affordable, multi-sector emission reductions by 2030 comparable to the US NDC. Second, we can begin to lay the foundation necessary to achieve the deeper emission reductions needed by 2050. The earlier we start, the more progress we can make to reduce emissions and, equally important, the more affordable the cost. Energy efficiency can contribute significant emission reductions in the electricity, transportation, industrial and buildings sectors. Fuel switching, particularly electrification, is another major source of emission reductions. At the same time, major technology advancements and deployment in areas such as CCUS, storage, and smart technologies can be achieved in 10 years.

Question 7: One of my concerns is ensuring that the Department of Energy and our national labs are fostering innovative technologies from concept all the way to commercialization. It seems to me that our national lab system provides the perfect environment to connect interrelated technologies that can be developed in collaborative way with businesses and universities. It is often these partnerships that allow maturing technologies to succeed.

How can we ensure that funding to labs is not spread too thin and we are focused on getting promising technologies across the finish line?

Answer 7: In January 2017, DOE published its groundbreaking report, *Annual Report on the State of the DOE National Laboratories*. The report recognizes the importance of ensuring "the relationship between DOE and its Laboratories, and thereby the efficiency and effectiveness of the Laboratories, are sustained and having lasting impact". The report makes two recommendations which I believe would address your concern that we ensure the effieicny and effectiveness of the labs:

> **Annual Report on the State of the DOE National Laboratories**: DOE plans to update this inaugural report each year to highlight new results and improvements, and discuss the status of actions taken to improve the Laboratory System and the strategic relationship with DOE.
>
> **DOE Transition Plan**: The Transition Plan prepared for the new administration describes the improvements and identifies the actions that if supported will lead to further progress for the DOE National Laboratory System.

Chapter 7 provides additional recommendations, including:

> **Clarifying roles/responsibilities:** Several external reviews (including the SEAB Task Force on DOE National Laboratories and CRENEL) have indicated that DOE should provide better clarification regarding roles/ responsibilities at DOE and particularly as it relates to the National Laboratories. The Department developed a policy, which articulates core management principles that clarify roles and responsibilities with respect to the National Laboratories. Programs have

implemented reforms in this area as well. For instance, NNSA issued a Supplemental Directive on site governance, which clarifies roles and responsibilities in NNSA.

Laboratory Planning Improvements: Planning has already begun for improvements to the second round of Plans for all 17 Labs incorporating lessons from the first year. A pilot is underway with NREL in which the Laboratory presented their overall LDRD plan, and will approve individual projects within that approved framework. The pilot for LDRD will be expanded to include the ten Science Labs and the INL.

Technology Transfer Execution Plan: The Plan and an associated policy are being drafted to identify actions that can further enhance the transition of R&D results out of the Laboratories.

Revolutionary and Evolutionary Working Group Evaluations: The next steps are to evaluate the success of the changes made, and in parallel, to determine what elements and what processes are appropriate for implementation at other Laboratories. The LOB will facilitate sharing of lessons learned, and will look to whether elements of these pilots may be applicable more broadly within the Department.

Strategic Partnership Projects (SPPs): The SPP working group will continue to promulgate best practices and examine policies and procedures to ensure efficiency and effectiveness.

DOE-Laboratory Crosscuts: The Department will continue its efforts to better coordinate and align strengths and activities throughout the DOE and Laboratory complex through the use of programmatic crosscuts.

Secretary of Energy Advisory Board (SEAB): Recent external evaluations of the DOE, such as the CRENEL and Mies-Augustine reports, noted the large number of similar evaluations that had been conducted on the National Laboratories over the past 50 years. SEAB is a Federal Advisory Committee, composed of external members, that provides advice and recommendations to the Secretary. The SEAB National Laboratory Task Force has been charged by the Secretary to review the progress of the Department's implementation of its response to the CRENEL and Mies-Augustine reports. This review is ongoing, and SEAB provides its assessment at the public SEAB meetings. Going forward, SEAB can continue to fill that role by periodically reviewing the implementation of actions derived from previous reports and offering further recommendations that build on the previous results.

CRENEL Effectiveness Review: In its response to the CRENEL report, the Department committed that the LOB will conduct a review of the effectiveness of CRENEL Implementation before February 2018.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Deborah L. Wince-Smith

Questions from Chairman Lisa Murkowski

Question 1: Over the past several years, the Department of Energy has made great strides in coordinating research efforts and encouraging inter-office collaboration. In order to get the greatest use from the taxpayer dollar, what can be done within DOE and across the government to make the most efficient use of resources to accelerate innovation for high priority clean energy technology research?

Collaboration and communication between agencies and offices within the Department is an important step and I agree the Department is making great strides in this area. Reaching outside of government to engage stakeholders in industry and academia will also facilitate greater uptake on investments in clean technology, as well as better align research to fields of commercial interest.

Question 2: I believe that microgrids offer an enormous opportunity for increasing the deployment of various clean energy technologies – from micro-reactors and marine hydrokinetics to wind and solar. The Department should increase efforts in this area to conduct more microgrid systems research that will de-risk microgrid technologies and emerging micro-generation options. It should build off the great work of the Grid Modernization Lab Consortium to take advantage of the early deployment opportunities that exist in today's operating microgrids, like the many in my home state of Alaska.

a. What do you believe is the value proposition for microgrids in accelerating our clean energy future?

   Microgrids can be important test beds for new energy technologies and uses. Further, their ability to decouple from the grid provides important redundancy and resilience in the event of manmade or natural disasters or cyber-attacks.

b. Should the Department conduct an amped-up cross-cutting microgrid research program to take advantage of these opportunities?

   I am not familiar enough with the Departments efforts in this area to comment.

Question 3: Swedish mining company LKAB and its Norwegian partner are developing a carbon dioxide-free process for steel production and mining. Iceland has a "no waste" mantra, including a carbon recycling plant that turns carbon dioxide from a nearby geothermal power plant into methanol for vehicle fuel. There is a lot of energy innovation happening in the Arctic, often by necessity. Is the United States doing anything similar to these types of activities, and are there other areas where we could be learning from our international partners?

What the U.S. should be learning from international efforts such as the ones you highlight is that competition for leadership in the clean tech space is ramping up and that if we do not strategically engage and invest in these fields, we risk losing that leadership, as well as economic value and national security.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Deborah L. Wince-Smith

Question 4: During the recent Arctic Frontiers Conference held in Norway, a Swedish Arctic energy company CEO announced a major project developing zero-carbon mining. He anticipates mining and tunnel operations being carbon-free in the next five to ten years at a specific site. Mining is certainly a challenging sector from an emissions perspective. Are there technologies being investigated in the U.S. that could lower carbon emissions from mining operations?

Question 5: In 1992, U.S. investors led with 97 percent of $2 billion in venture finance; in 2017, U.S. investors led with 44 percent of $154 billion in venture finance, with Asian investors accounting for 40 percent. In your view, what has caused that decline in U.S. global venture capital share? How can we go about reversing that trend?

It may be too late to reverse this trend, not because the U.S. isn't a major player in the venture finance world, but because other nations have significantly ramped up their investments. Again, I'd argue that strategic investments in longer term, more patient capital will be critical, and it may be that public/private partnerships are required to make this happen on the scale and scope necessary.

Question 6: What are the most promising developments in carbon capture, utilization, and sequestration innovation and can you tell me more about the role these technologies will play in the future? Furthermore, in order to get the Department of Energy set up for success in developing these technologies, what policy changes would you suggest?

CCS technologies must be viewed as a potential new market and leadership opportunity for the United States, not a cost add-on. It's clear that the United States and rest of the world are headed towards a carbon neutral/reduced carbon environment and the sooner this is recognized as not only an environmental issue, but also one of economic opportunity, the better positioned the U.S. will be to lead.

Question 7: We have already seen China take solar technology that was invented in U.S. labs and commercialize it at scale in a way that floods international markets and increases China's position as a dominant exporter of clean energy technology. We are watching them replicate this success with battery technology and the critical mineral supply chain that underpins both technologies. Finally China is pushing aggressively on advanced nuclear with the intention of dominating global nuclear markets as well.

a. Can you explain to us what the long-term effects of these trends will be?

   If left unchecked by scattershot and inadequate investment, the U.S. risks losing market share and economic value across these myriad industries.

b. What will happen to U.S. manufacturing and the workforce?

   Both will suffer.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to the Honorable Deborah L. Wince-Smith

Question 8: You referenced several reports authored by the Council on Competitiveness that highlight advancements in industrial sector innovation. We understand that there are more opportunities to improve manufacturing processes and increase efficiency, but that some further innovation will be required.

What are the promising technologies, in terms of low-carbon heat production and advanced manufacturing that you anticipate relying on to solve these challenges?

Sensing technologies and big data collections and analytics will be key to reaping the potential efficiencies of advanced manufacturing. Data set validation, computing power, and education are all important pieces of this equation. Overlaying all of the technologies must be strong built-in cyber protections.

Question 9: As we consider ways to encourage more U.S. investment in energy technology innovation, how do you view the potential roles for technologies like off-shore wind and marine renewable energy sources like wave and tidal?

The Council has long held the position that "energy is everything" and that we should utilize all sources of energy to meet growing energy needs and ensure a diversified ecosystem both for the economic opportunity new technologies hold as well as the resilience they can provide.

Question 10: Micro-reactors have the potential to lower the cost of electricity, increase reliability and resilience, and decrease emissions for many challenging applications. These advanced reactors would compete with the diesel generator market and could transform life for remote communities, provide stability to military installations, and even make mining or mineral development operations economically viable.

a. What is the potential for these promising micro-reactors?

   I would agree with the premise described in the question.

b. What are your chief policy concerns relating to getting these micro-reactors to market?

   Safety and security.

Question 11: I understand that today's technologies are finding economic applications on the grid and in electric vehicles. We have heard at previous hearings about the limitations of today's technologies and the importance of developing next-generation storage.

a. What are the most promising energy storage technologies under development today?
b. How could efforts be accelerated for these important technologies?

   I think issues surrounding product liability need to be looked at with regard to battery technology and collaborations such as the Joint Center for Energy Storage Research (JCESR) should be supported with long term stable funding.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: ***The Status and Outlook of Energy Innovation in the United States***
Questions for the Record Submitted to Mr. Jay Faison

Questions from Chairman Lisa Murkowski

Question 1: Over the past several years, the Department of Energy has made great strides in coordinating research efforts and encouraging inter-office collaboration. In order to get the greatest use from the taxpayer dollar, what can be done within DOE and across the government to make the most efficient use of resources to accelerate innovation for high priority clean energy technology research?

Ambitious goals, similar to JFK's famous "Moonshot" program, are needed to align the Department of Energy's vast research capabilities and resources. Focusing taxpayer dollars is critical to ensuring that projects are not spread one-mile wide and an inch deep. To reduce redundancies, the Department of Energy should build on its recent efforts to increase coordination between its offices and maximize the benefits of system-based integration between relevant agencies and offices.

Technology developments in the laboratory provide little public benefit if they cannot be commercialized. By partnering with the private sector, targeted federal support can offset the high capital costs and first-of-a-kind commercial risks commonly associated with novel energy sector projects. Additionally, public private partnerships can identify rules and regulations that may constrain deployment.

Question 2: I believe that microgrids offer an enormous opportunity for increasing the deployment of various clean energy technologies – from micro-reactors and marine hydrokinetics to wind and solar. The Department should increase efforts in this area to conduct more microgrid systems research that will de-risk microgrid technologies and emerging micro-generation options. It should build off the great work of the Grid Modernization Lab Consortium to take advantage of the early deployment opportunities that exist in today's operating microgrids, like the many in my home state of Alaska.

a. What do you believe is the value proposition for microgrids in accelerating our clean energy future?

Smart microgrids enable the integration of a wide variety of distributed energy resources (DERs) such as solar, wind, energy storage or even microreactors more feasible. Microgrids can increase reliability and affordability relative to the traditional electric grid, particularly for remote communities such as areas outside of the Railbelt in Alaska.

b. Should the Department conduct an amped-up crosscutting microgrid research program to take advantage of these opportunities?

The Department of Energy should look for opportunities to integrate crosscutting microgrid and smart grid research into relevant technology research areas. Maintaining siloed research centers in the Office of Electricity reduces the potential commercial impact of research. A larger program of research and demonstration into advanced microgrid technologies could accelerate the deployment

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: ***The Status and Outlook of Energy Innovation in the United States***
Questions for the Record Submitted to Mr. Jay Faison

of DERs. The Department should focus demonstration activities in regions that need the most support, such as those in Alaska.

Question 3: There is no question in my mind that advanced nuclear should be part of any energy solution. One reason for this is the tremendous amount of emission free energy that they can provide. Leading on advanced nuclear will also reassert our role on the world stage in developing non-proliferation policies and ensure a viable nuclear workforce here at home. How do you see advanced nuclear fitting into the clean energy mix both here in the United States and around the world?

A recent MIT report on nuclear energy found that decarbonization is substantially cheaper when nuclear is included in the mix. Advanced nuclear power is a critical part of a zero-emission future and the United States should remain a key player in bringing these technologies to market. American companies are developing many advanced nuclear technologies, such as small modular reactors (SMRs) and non-light water reactors (NLWRs). Continued innovation in these new technologies would provide tremendous economic opportunities for use in the United States and for export abroad.

Advanced reactors provide new opportunities for nuclear energy technology that can't be met by current technologies. Most advanced reactors are smaller than existing reactors, allowing them to access new markets too small for gigawatt scale plants. Other advanced reactor such as high-temperature gas reactors and molten salt reactors operate at much higher temperatures than light water reactors and have the potential to higher zero-carbon high temperature process heat for industrial purposes, or for district heating. A majority of carbon emissions are outside of the power sector, so developing technologies the can target opportunities in industrial or building sector emissions, as well as electricity, is crucial.

Question 4: Swedish mining company LKAB and its Norwegian partner are developing a carbon dioxide-free process for steel production and mining. Iceland has a "no waste" mantra, including a carbon recycling plant that turns carbon dioxide from a nearby geothermal power plant into methanol for vehicle fuel. There is a lot of energy innovation happening in the Arctic, often by necessity. Is the United States doing anything similar to these types of activities, and are there other areas where we could be learning from our international partners?

The Office of Fossil Energy has previously supported large scale demonstrations of low-carbon industrial projects through the Industrial Carbon Capture and Storage (ICCS) program. Although successful projects were developed as a result of ICCS, most industrial research within DOE does not focus on creating products with low to zero-carbon emissions. The Department of Energy's Advanced Manufacturing Office (AMO) is dedicated to increasing the efficiency, productivity and competitiveness of manufacturers across the industrial sector. Building on this expertise, more research is needed to develop technologies consistent with deep decarbonization, such as process electrification, hydrogen utilization and carbon capture. Other countries are focusing on carbon capture as a means to decarbonize the industrial sector, in part because very few alternatives exist.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: ***The Status and Outlook of Energy Innovation in the United States***
Questions for the Record Submitted to Mr. Jay Faison

The United States should emulate this approach and focus on economic ways carbon capture systems can be integrated into existing industrial processes.

To date, the Advanced Manufacturing Office has studied over a dozen different industries to estimate the potential energy savings of using state of the art technologies, or those close to commercialization. Limited research is also being conducted within the Bioenergy Technology Office and the Office of Fossil Energy to convert carbon dioxide into products such as fuels and materials.

Question 5: During the recent Arctic Frontiers Conference held in Norway, a Swedish Arctic energy company CEO announced a major project developing zero-carbon mining. He anticipates mining and tunnel operations being carbon-free in the next five to ten years at a specific site. Mining is certainly a challenging sector from an emissions perspective. Are there technologies being investigated in the U.S. that could lower carbon emissions from mining operations?

Yes, and more can be done to accelerate their deployment. For example, the Environmental Protection Agency runs a program called the Coalbed Methane Outreach Program (CMOP) to reduce methane emissions from coal mines. Among other functions, the program provides technical assistance to mining companies, analyzes and demonstrates technologies, and conducts feasibility assessments. Similar to how carbon dioxide can be injected into oil reservoirs to produce additional oil, carbon dioxide can also be injected into unmineable coal seams to produce methane in a process called "enhanced coal bed methane recovery". Emerging types of distributed power generation, such as microreactors could also play a role in decarbonizing mining operations.

Question 6: What are the most promising developments in carbon capture, utilization, and sequestration innovation and can you tell me more about the role these technologies will play in the future? Furthermore, in order to get the Department of Energy set up for success in developing these technologies, what policy changes would you suggest?

From an industry perspective, Congress' recent enactment of the changes to the section 45Q tax credit has reinvigorated industry interest in commercializing and deploying carbon capture technologies. Prior to this incentive, there were virtually no significant incentives for carbon capture projects. These updates are expected to be a main driver in projects ranging from the new zero-emission Allam Cycle power plant being demonstrated in Texas, to the Lake Charles Methanol facility in Louisiana, to the Project Tundra coal retrofit project in North Dakota. In each case, grants and other collaboration with Department of Energy has accelerated development from basic R&D to loan guarantees. The Department should continue to support technologies across the development cycle and apply its carbon capture expertise to a wider range of power sources and industries.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. Jay Faison

Question 7: As we consider ways to encourage more U.S. investment in energy technology innovation, how do you view the potential roles for technologies like off-shore wind and marine renewable energy sources like wave and tidal?

These technologies have vast potential to increase renewable electricity generation while playing a key role in decarbonization. As with all renewable resources, there are still concerns regarding variability; however, the technical potential for both off-shore wind and marine resources is significant. A study from the Bureau of Ocean Energy Management, the DOE, and the U.S. Department of Interior shows a technical potential of offshore wind at 2,058 GW, almost double the current electricity generation in the U.S., based on the year 2015.[1] This is not a new technology as offshore wind has been successfully deployed since 1991 in Europe. Technological innovation continues to allow for additional opportunities even in the United States, where there is commercial deployment in the Northeast. Marine resources in the United States are still undergoing testing and development, but have the potential to significantly breakthrough as a reliable resource. According to the Water Power Technology Office, at the DOE, there is the technical potential of 1,285 - 1,846 TWh per year of generation from marine resources.[2] In both cases, these are great resources for coastal communities, and can be utilized as needed or stored for later use if combined with storage. To further these technologies, continued research, technology innovation, and reduced costs would help accelerate these technologies.

Question 8: Micro-reactors have the potential to lower the cost of electricity, increase reliability and resilience, and decrease emissions for many challenging applications. These advanced reactors would compete with the diesel generator market and could transform life for remote communities, provide stability to military installations, and even make mining or mineral development operations economically viable.

a. What is the potential for these promising micro-reactors?

Nuclear microreactors can operate for continuously for several years without refueling and operate at an unparalleled level of energy reliability similar to the U.S. Navy submarine fleet. These reactors may also offer cost and environmental benefits over diesel generators in rural communities and other regions disconnected from conventional power sources. Many technologies are also being engineered in America. Multiple companies are commercializing microreactor designs in the U.S. including Oklo, X-energy, NuScale Power, Westinghouse, and General Atomics.

b. What are your chief policy concerns relating to getting these micro-reactors to market?

A chief concern is that micro-reactor developers lack access to advanced nuclear fuels in the United States. This type of advanced fuel, known as "High-Assay Low Enriched Uranium" (HALEU), is

[1] https://www.boem.gov/National-Offshore-Wind-Strategy/
[2] https://www.energy.gov/eere/water/marine-and-hydrokinetic-resource-assessment-and-characterization

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. Jay Faison

needed for both demonstrating proof of concept and operating a commercial facility. In the short-term, the fuel supply will likely be derived from the federal contracts and capabilities until a private supply chain can emerge. Corresponding federal regulations, such as certified transportation methods of HALEU, will need to be developed.

Further, rightsizing regulatory requirements to the operational characteristics and risk profiles of new microreactor designs is necessary, which can be informed by data generated at the National Reactor Innovation Center.

Question 9: I understand that today's technologies are finding economic applications on the grid and in electric vehicles. We have heard at previous hearings about the limitations of today's technologies and the importance of developing next-generation storage.

a. What are the most promising energy storage technologies under development today?

Thermal energy storage, compressed (air or liquid) energy storage and flow batteries are three of the most promising energy storage technologies. These are designed for longer duration storage than conventional batteries today, as well as multiple charge and discharge cycles.

b. How could efforts be accelerated for these important technologies?

Further cost reductions through research and development will play a pivotal role. Similar to other novel technologies, federal resources can support early-stage research through grid-scale demonstration projects. Public private partnerships should also focus on identifying market opportunities and future grid needs to inform earlier stage research.

Question 10: We have heard many predictions about the adoption of electric vehicles. Many experts believe that these vehicles and in some cases hydrogen fuel cell-powered transportation could lead to a decrease in emissions from vehicles on our roads. At the same time, some innovators are pursuing advanced biofuels for difficult transportation subsectors like aviation.

What do you think the timeline is for these changes in the transportation sector to be widely adopted and make an impact on global emissions?

Hydrogen: According to a 2017 report from the Hydrogen Council, a group consisting of the largest automakers and energy companies, hydrogen could power significant shares of the world's transportation fleets. By 2050, they estimate the market for hydrogen to be 400 million cars, 20 million trucks and 5 million buses. In all, they forecast that hydrogen can help avoid more than 3.2 gigatons of carbon dioxide each year by 2050.[3] Despite the limited availability of hydrogen fueling infrastructure, automakers have already released hydrogen fuel cell vehicle models in the United

[3] http://hydrogencouncil.com/study-hydrogen-scaling-up/

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: ***The Status and Outlook of Energy Innovation in the United States***
Questions for the Record Submitted to Mr. Jay Faison

States, such as the Toyota Mirai, the Hyundai Tucson and Honda Clarity. A few hydrogen projects outside of the light duty vehicle segment, including Toyota's hydrogen heavy-duty truck pilot at the Port of Long Beach[4] and Viking Cruises' hydrogen-powered liner.

Biofuels: Biofuels have significant potential for decarbonizing transportation emissions. At the same time, as the quantity of sustainable biomass available for biofuels production is limited, it needs to be geared towards the highest impact use cases. DOE's *2016 One Billion Ton* study estimates that economically viable biomass options could eventually offset 20% of U.S. oil consumption, demonstrated the limited quantity of future biofuel availability. Many biofuels can be designed as "drop-in equivalents", and can be in many cases substituted 1:1 for fuels produced from petroleum. Biofuels are particularly well suited for applications in hard to abate sectors such as aviation decarbonization. Jet fuel can be synthesized from biological sources to replace petroleum-based liquid fuels. The International Air Transport Association (IATA) is committed to reducing aviations emissions by 50% by 2050 – a difficult task when air traffic is expected to dramatically increase during that period. It is highly unlikely that batteries or hydrogen can be used to decarbonize long-haul aviation, due to the density and volume limitations they respectively face. Bio-based jet fuels are currently twice as expensive as jet fuel, but with additional R&D and scale could be brought down to within $1 per gallon of current jet fuel prices. Due to these challenges, without a large increase in R&D, it is likely that most emissions reduction activities in aviation will focus on efficiency until 2040.

Electric Vehicles: Electric vehicles will help reduce emissions from vehicles on roads, primarily because they are more efficient per mile travelled. Electric vehicle emissions come from their source of charge - how and when it is charged. In the United States, fossil fuels are the primary source of electricity so electric vehicles are not emissions free. Thus, the rate of power sector decarbonization is a critical factor. Each country will have a different rate of electric vehicle adoption. Some countries are moving to ban internal combustion engine vehicles or requiring a certain percentage of electric vehicles on the road. Globally, the rate of electric vehicle adoption will likely depend on its ability to compete with traditional internal combustion engines on key factors such as range, refueling time and cost. Even as electric vehicles continue to rapidly become cost competitive to own, other factors may facilitate adoption such as changes in driving patterns, ownership and the cost of electricity relative to hydrocarbon fuels. Research from Bloomberg New Energy Finance estimates 2040 to be a year where electric vehicles will make up more than 50% of the new car sales in the market.[5] This study illustrates global market changes while discussing concerns such as charging infrastructure, fleet turnover and cobalt sourcing concerns. Other reports indicate hybrids may play a larger role in combination with EVs to reduce the number of ICE vehicles,

[4] https://global.toyota/en/newsroom/corporate/23722307.html
[5] https://about.bnef.com/electric-vehicle-outlook/

liquid fuels are expected to remain competitive due to high energy density, and the existing fueling infrastructure.[6]

Questions from Ranking Member Joe Manchin III

Questions: It is clear that as technologies continue to develop, energy storage and batteries will be critical to ensuring increasing U.S. energy independence and security. However, these batteries require raw materials and critical minerals that are both in limited supply, and can cause great harm to our environment. While 99% of lead acid batteries are recycled, we are still lacking the technology and infrastructure to do the same for next generation batteries, like lithium-ion.

a. What happens to these batteries when they reach their end-of-life?

Current recycling involves repurposing lithium-ion batteries for use in other applications, from home energy storage, electric vehicle charging, to renewables and storage integration.

b. What needs to be done to ensure that we are prepared to properly handle the disposal and recycling of next generation batteries?

Research should be targeted at developing ways to maximize value from the byproducts of spent batteries to encourage the development of a robust recycling market. For example, one patent-pending technology developed out of UC San Diego research collects cobalt for reuse without losing performance.

Questions from Senator John Hoeven

Question 1: You mention the global demand for coal and natural gas, which are projected to provide 45% of our total energy needs in 2030 and could grow to nearly 50% by 2040. Accelerating the research and development of advanced fossil energy and carbon capture technologies is essential to maximizing abundant American resources, reducing global emissions, and growing U.S. geopolitical strength. I believe that strong public private partnerships prove critical in commercializing new technologies.

For example, the Energy and Environmental Research Center (EERC) is currently partnering with DOE to design, build, and operate a direct-fired, supercritical CO2 cycle pilot plant. This breakthrough Allam Cycle design is an exciting innovation in the fossil program.

[6] https://news.ihsmarkit.com/press-release/energy-power-media/future-cars-2040-miles-traveled-will-soar-while-sales-new-vehicles-

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: ***The Status and Outlook of Energy Innovation in the United States***
Questions for the Record Submitted to Mr. Jay Faison

How can the federal energy innovation apparatus better utilize resources to advance energy innovation and make our vast fossil energy resources cleaner, more reliable, more affordable while creating U.S. jobs?

Ambitious goals, similar to JFK's famous "Moonshot" program, are needed to align the Department of Energy's vast research capabilities and resources. Focusing taxpayer dollars is critical to ensuring that projects are not spread one-mile wide and an inch deep. To reduce redundancies, the Department of Energy should build on its recent efforts to increase coordination between its offices and maximize the benefits of system-based integration between relevant agencies and offices.

Technology developments in the laboratory provide little public benefit if they cannot be commercialized. By partnering with the private sector, targeted federal support can offset the high capital costs and first-of-a-kind commercial risks commonly associated with novel energy sector projects. Additionally, public private partnerships can identify rules and regulations that may constrain deployment.

Question 2: Would you recommend broadening the scope of the Office of Fossil Energy's low-carbon research program to more sources, including coal and natural gas power plants, and industrial facilities to maximize the environmental and economic potential?

The United States is blessed with a wealth of natural resources. At current production rates, we have enough natural gas for nearly a century[7] and several centuries worth of coal.[8] It is in our best interest to develop technologies, for both power generation and industrial processes, that can enable the long-term utilization of these resources in a way that complements a low-carbon future. With Congress' recent changes to the section 45Q tax credit, there is now a significant incentive for carbon capture projects, including those in the industrial sector. One problem is that carbon capture technologies have not been explored by most industries. Applying the Office of Fossil Energy's carbon capture expertise to industrial systems is a logical extension of their capabilities. Further, industrial carbon capture would also complement previous Energy Efficiency and Renewable Energy (EERE) research. For example, EERE through its Advanced Manufacturing Office, invested $320 million dollars to improving the energy efficiency of industrial systems in FY2019.

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[7] https://www.americangeosciences.org/critical-issues/faq/how-much-natural-gas-does-united-states-have-and-how-long-will-it-last
[8] https://www.eia.gov/energyexplained/index.php?page=coal_reserves

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. Jason Grumet

Questions from Chairman Lisa Murkowski

Question 1: Over the past several years, the Department of Energy has made great strides in coordinating research efforts and encouraging inter-office collaboration. In order to get the greatest use from the taxpayer dollar, what can be done within DOE and across the government to make the most efficient use of resources to accelerate innovation for high priority clean energy technology research?

Today one of the most effective vehicles for supporting high priority clean energy technology research is the Advanced Research Projects Agency – Energy (ARPA-E). Because of its organizational design principals including special hiring authority, ability to use multiple contracting mechanisms, and ability to cancel projects and move money around within a given portfolio to more promising avenues, ARPA-E stands alone as a model for efficiency in accelerating innovation. As such one of the most important things that the Committee on Energy and Natural Resources can do is support a re-authorization bill for ARPA-E that is true to the original authorization's principals, and reconfirming ARPA-E's ability to also support demonstration-scale projects as follow-on support for successful projects that are not yet commercializable due to engineering, manufacturing and financial risks at commercial scale. I would also recommend that ARPA-E's authorizations be increased to be in line with the AEIC's recommendation of $1 billion per year, with a plan to work with appropriators to increase ARPA-E's appropriations to that level.

Beyond ARPA-E, similar flexibility in contracting, cancelation and re-awarding of R&D money should be employed in other DOE technology offices to enable flexibility and responsiveness to the uncertain nature of energy technology R&D.

Question 2: I believe that microgrids offer an enormous opportunity for increasing the deployment of various clean energy technologies – from micro-reactors and marine hydrokinetics to wind and solar. The Department should increase efforts in this area to conduct more microgrid systems research that will de-risk microgrid technologies and emerging micro-generation options. It should build off the great work of the Grid Modernization Lab Consortium to take advantage of the early deployment opportunities that exist in today's operating microgrids, like the many in my home state of Alaska.

a. What do you believe is the value proposition for microgrids in accelerating our clean energy future?

   Microgrids will continue to play an important role in remote (off-grid) communities, and critical installations such as military bases and hospitals where back-up resilience is of critical importance. Additionally, at the neighborhood/campus level they will continue to play an important role, particularly where local generation capabilities such as co-gen plants and back-up generators are in-use. If a clean energy future relies heavily distributed energy resources (DERs), then microgrids will play an increasingly important role in maintaining grid reliability through the creation of redundant local distribution grids with the ability to locally control and optimize the integration of generation such as roof-top solar, wind and storage. Five years ago, the energy community was much less bullish on the role of micro-grids to enable a clean energy transition, however given the evolving costs of DER renewables with storage to be potentially at parity, or a small premium (15-

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. Jason Grumet

20%) over centralized renewable generation, and the improvement of standardized microgrid control technologies, versus the previously bespoke efforts initiated by DOD and DOE for military bases, it is clear that a distributed microgrid model might offer a more resilient approach to infrastructure to enable a clean energy future.

b. Should the Department conduct an amped-up cross-cutting microgrid research program to take advantage of these opportunities?

   It is not likely that a full-on "amped-up" cross-cut would be required. This type of R&D would comfortably fit into the Office of Electricity's (OE) mandate and expertise. To increase commercialization opportunities and connections to industry, an appropriation to OE to work on microgrids could include a requirement similar to ARPA-E funding that 5% of activities in the portfolio are focused on tech-to-market/commercialization activities. One way to ensure this is to create a small cross-cut that includes OE and Office of Technology Transitions as their commercialization and industrial convening partner.

Question 3: Swedish mining company LKAB and its Norwegian partner are developing a carbon dioxide-free process for steel production and mining. Iceland has a "no waste" mantra, including a carbon recycling plant that turns carbon dioxide from a nearby geothermal power plant into methanol for vehicle fuel. There is a lot of energy innovation happening in the Arctic, often by necessity. Is the United States doing anything similar to these types of activities, and are there other areas where we could be learning from our international partners?

Recently, Breakthrough Energy Ventures led a significant investment round in Boston Metal, a Massachusetts-based company which is developing an electrical process for producing iron and steel, significantly reducing emissions.[1] Further, ARPA-E and cyclotron road has supported research into carbon dioxide utilization, such as reduction to carbon monoxide as a feedstock for the production of fuels and chemicals. These are areas that are currently underfunded in the US and pose an opportunity for increased investment and partnership with international partners.

Question 4: During the recent Arctic Frontiers Conference held in Norway, a Swedish Arctic energy company CEO announced a major project developing zero-carbon mining. He anticipates mining and tunnel operations being carbon-free in the next five to ten years at a specific site. Mining is certainly a challenging sector from an emissions perspective. Are there technologies being investigated in the U.S. that could lower carbon emissions from mining operations?

There has not, to our team's knowledge, been a comprehensive program focusing on reducing emissions from mining and other extractive industries. The most similar technology development activity supported by the Department of Energy is ARPA-E's MONITOR program. In this program, remote methane sensing technologies are under development to identify leaks from natural gas wells, fields and infrastructure due

[1] http://fortune.com/2019/01/09/boston-metal/

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. Jason Grumet

to it's potency as a green house gas. Similar monitoring technologies may be required for tracking emissions from mining as well.

Question 5: What are the most promising developments in carbon capture, utilization, and sequestration innovation and can you tell me more about the role these technologies will play in the future? Furthermore, in order to get the Department of Energy set up for success in developing these technologies, what policy changes would you suggest?

Net Power's so-called Allam cycle is an important technology both from the standpoint that it can theoretically achieve 100% capture of produced CO_2, but also because Net Power has been capable of lining up capital to do a full-scale demonstration plant, which is critical to proving this technologies capability and long-term economic viability.

Technologies developed in ARPA-E's IMPACCT program, which was initiated in 2010, are capable of being used in a retrofit approach for existing coal-fired power plants. A critical technology area that, until that point, had little funding. These technologies represent some "shelved" technologies ready for further development and demonstration support and offer an approach to continue to utilized today's coal-fired generation fleet for years to come.

The development of Utilization technologies will be by far the most challenging areas to develop cost-competitive technologies. Carbon dioxide is the product of a strongly exothermic reactions of carbon-containing fuels (hence why we use it to produce so much heat for power plants and thermal applications), and the reduction of carbon dioxide to carbon monoxide and further to carbon and hydrocarbon materials, represents a major enthalpic and entropic challenge. Electrochemical reduction techniques and photochemical techniques are unlikely ever to be competitive at scale. Rather, investigation into high-temperature thermocatalytic reduction of carbon dioxide to carbon monoxide should be investigated.

Perhaps the most promising approach to CCUS for natural gas is through methane pyrolysis:

$$CH_4 \xrightarrow{heat} C(s) + 2H_2$$

Where methane is chemically separated at high temperatures to a solid carbon allotrope and gaseous hydrogen. Then, hydrogen can be used as a fuel (combusted for heat/power or marketed as a transportation fuel) while the solid carbon can be used as a material for construction or even electronics. The major unexplored challenge at this point is being able to control the form of the solid carbon produced, though evidence has shown that everything from nano-tubes to amorphous carbon black can be produced. Three projects were funded in this space in the 2018 ARPA-E OPEN FOA.

A key critical challenge in carbon capture is the development of cost-competitive, scalable direct air capture technologies. A number of researchers and private ventures have been working on addressing the technology challenges and pathways to being able to capture CO_2 for under $100 per ton have been identified. Continued support of this work is critical, as it bridges both our economic and environmental policy goals.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. Jason Grumet

Question 6: As we consider ways to encourage more U.S. investment in energy technology innovation, how do you view the potential roles for technologies like off-shore wind and marine renewable energy sources like wave and tidal?

Recent PPAs signed in New England for off-shore wind development almost defy belief, yet demonstrate the incredible learning curve that has been experienced by the industry. Much credit is owed to the team at Deepwater Wind who developed the first off-shore wind farm in the US, Block Island Wind, off of Block Island, Rhode Island. It is important to note, however, that the Long Island and Nantucket Sounds are particularly friendly to building off-shore infrastructure due to the relatively shallow waters and protection from major seas. To see the same success on the pacific coast, or further exploitation of off-shore wind resources beyond the near-shore shallow waters, further research will be required into better floating turbines, and multi-modal energy extraction technologies, such as wind and wave combined. Tidal will perhaps be the most challenging technology to develop, from an ecological perspective, because it requires capturing and controlling a large inflow and outflow of water from bays and extracting energy from them. In doing this large-scale terraforming of important ecosystems, there is a chance that marine life could be greatly affected, indirectly harming fisheries and the health of coastal environments.

Question 7: Micro-reactors have the potential to lower the cost of electricity, increase reliability and resilience, and decrease emissions for many challenging applications. These advanced reactors would compete with the diesel generator market and could transform life for remote communities, provide stability to military installations, and even make mining or mineral development operations economically viable.

a. What is the potential for these promising micro-reactors?

   Micro-reactors – commonly defined as modular fission reactors sized in the 1-10MW scale – have the potential to offer clean, reliable power at the local scale, whether within the grid or off-the-grid. Multiple commercial entities from small start-ups to large engineering houses have been focusing on the R&D and Front End Engineering Design (FEED) of these systems. Likely, these systems would be most impactful in remote communities on microgrids, and on military and national lab installations. In all likelihood a demonstration would take place at Idaho National Laboratory first. Further, the DOD has shown keen interest in these technologies and has made it part of their technical capabilities plans.

   In the most aggressively optimistic scenarios, an engineering demonstration system (where electrical heat is used rather than fissile material) may be built in 2-3 years, with a fully powered demonstration underway in 5 years. Realistically, these timelines could be 2-3x as long without serious policy engagement.

b. What are your chief policy concerns relating to getting these micro-reactors to market?

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. Jason Grumet

Federal funding of further development and demonstration of these technologies are critical to achieve an accelerated technology development schedule. Further, congress should direct the DOE to work with the DOD to develop a plan to demonstrate these technologies on a military installation and at INL.

An additional concern is the need for sufficient resources at NRC to review these designs so no regulatory delay is experienced.

Question 8: I understand that today's technologies are finding economic applications on the grid and in electric vehicles. We have heard at previous hearings about the limitations of today's technologies and the importance of developing next-generation storage.

a. What are the most promising energy storage technologies under development today?

   A key challenge that must be addressed when contemplating a high percentage of renewables on the grid is the need for long-duration electricity storage as way to hedge against times when the renewables are incapable of generating power – such as a week with no sun or extended low wind conditions. Lithium ion technology is fundamentally incapable of providing the length of storage required in a cost-competitive way.

   High temperature thermal storage, and flow batteries are the most promising technological classes of technologies under development. These technologies have seen a major infusion of R&D capital from ARPA-E via the DAYS program and also multiple venture groups.

b. How could efforts be accelerated for these important technologies?

   Later stage R&D should be supported by DOE to continue development of technologies currently supported by ARPA-E DAYS. A public private partnership should be established between DOE and industry to do grid-scale demonstrations of these technologies in the next 3-6 years after critical technology de-risking has been achieved by DAYS.

Question 9: We have heard many predictions about the adoption of electric vehicles. Many experts believe that these vehicles and in some cases hydrogen fuel cell-powered transportation could lead to a decrease in emissions from vehicles on our roads. At the same time, some innovators are pursuing advanced biofuels for difficult transportation subsectors like aviation.

What do you think the timeline is for these changes in the transportation sector to be widely adopted and make an impact on global emissions?

Making such predictions are likely a fool's errand. However, you are right to ask these questions. Decreasing emissions in transportation will be an incredible challenge due to the slow turn-over of the stock of vehicles – the automotive fleet turn-over rate is longer than a decade, and today in Renton,

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. Jason Grumet

Washington one and a half new 737s roll off the assembly line every day with an expected life of thirty years. Thus, focusing on the development of low carbon fuels that are fungible with today's transportation fleet is critical to meet near- and mid-term emissions reductions. However, continued focus on electrification, and hydrogen power (with low-emission hydrogen from methane pyrolysis perhaps) of vehicles must remain the lodestar for long-term reductions in emissions. On the optimistic side, estimates are the worldwide production of EVs will go from 1.1M in 2017 to 11M in 2025 to 30M in 2030.[2] This is a massive US opportunity for emissions reductions from the auto sector, improved air quality, reductions in oil use, increased manufacturing, low consumer costs and many other benefits.

[2] Electric Vehicle Outlook 2018 | Bloomberg New Energy Finance: https://about.bnef.com/electric-vehicle-outlook/

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. James F. Wood

Question from Ranking Member Joe Manchin III

Question: According to the International Energy Agency (IEA), in 2017, the U.S. used coal for 31% of its electricity, and that number is forecast to continue to decline. In China, coal comprised 67% of the electricity mix, and 74% in India. While Asian countries are taking some steps to reduce carbon emissions, the IEA says coal will still comprise about 51% of the electricity mix in China, and 57% in India in 2040. I believe that we need to economically incentivize the world to use cleaner energy and to create a workforce in America that manufactures the next generation of energy technology.

Is the U.S. currently in a position to lead the world in developing the next generation of clean coal technologies? If not, why not?

Answer: The Energy Policy Act of 2005 included a number of incentives for developing clean coal including the Clean Coal Power Initiative (CCPI). By 2009, the U.S. Department of Energy announced three new projects with a value of $3.18 billion "to accelerate the development of advanced coal technologies with carbon capture and storage at commercial scale" (https://www.energy.gov/fe/clean-coal-power-initiative-round-iii).

Demonstration of large commercial scale projects is a requirement in order that owners and developers may secure financing for new technologies using performance and cost data from actual projects in operation. CCPI was designed to advance new technologies and to minimize the first of a kind (FOAK) risks associated with moving technology to a commercial scale. A short summary of several CCPI project outcomes is instructive:

1. The AEP project sought to capture 90% of a 235 MW slipstream of flue gas at the AEP 1300 MW Mountaineer facility. The technology vendor was Alstom, then a French-owned company. The captured CO_2 was to be compressed and sequestered underground. The Alstom chilled ammonia technology was being tested at pilot scale and the performance of that test was deemed unsuccessful by AEP, so it withdrew from the project and returned the funds to DOE;
2. The Summit Texas Clean Energy project intended to integrate a Siemens coal gasifier and electric power island and capture 90% of the CO_2 from the 400 MW facility using the Linde (German-owned) Rectisol capture system. The captured CO_2 was to be compressed and used for enhanced oil recovery in the Permian Basin. The developer, Summit, was unable to reach agreement on a fixed-price construction contract with U.S. or Chinese contractors, and therefore unable to close on financing and eventually DOE withdrew its cost share and Summit abandoned the project.
3. The Hydrogen Energy California (HECA) project, sponsored by British Petroleum (BP) was to gasify petroleum coke (at that time being exported to China from the U.S. West Coast) blended with various domestic coals to produce electric power from combusting hydrogen, and produce ammonia-based fertilizer for sale in the San Joaquin Valley. The carbon capture system design was to be Linde Rectisol. The captured CO_2 was to be used for enhanced oil recovery at the Occidental Petroleum Elk Hills oil field near Bakersfield (formerly owned by the U.S. Navy). The financial exposure created by the Deepwater Horizon oil spill caused BP to abandon the project. DOE found a replacement sponsor (SES Energy Concord, MA; now defunct) to undertake the development and SES selected Japan's MHI as the gasifier vendor. MHI was unwilling to guarantee performance

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. James F. Wood

using mixtures of coal and petroleum coke, the sponsor was undercapitalized and California was reluctant to issue permits on a project that used coal, so DOE withdrew support and the sponsor abandoned the project.

4. DOE announced the Petra Nova project (https://www.nrg.com/case-studies/petra-nova.html) in March 2010 as part of the American Recovery and Reinvestment Act. The project was sponsored by NRG Energy at its WA Parish power plant near Houston. After the award, NRG upsized the MHI capture system, acquired a nearby oil field, and constructed the project which is in operation today. Financing includes a joint venture with MHI, and a loan from Jexim (Japanese Export Import Agency). The capture system has met its performance guarantees, but the current economics of the project are questionable with oil at $50/bbl compared to near $100/bbl when the project proforma was created. The 45Q tax credit enacted in 2018 is not likely to significantly improve those economics because the credit is limited to that portion of the EOR gas that is retained in the formation, not the actual amount captured at the power plant.
5. The original FutureGen project consisted of an alliance of coal companies and the federal government. Federal cost share on the $1.65 billion project estimate was $1 billion. The project was to have been a coal gasification project sited in Mattoon, IL. The captured CO_2 was to have been injected in the Mount Simon saline aquifer. The project was restructured in 2012 by substituting an oxy-combustion and CO_2 capture system, and moving the location of the project to a closed Ameren facility in Meredosia, IL. DOE's logic for this change included: "Why award another gasification plant, when HECA and Summit are in trouble?" The oxy-combustion (B&W) and carbon capture (Air Liquide: French-owned) vendors had an alliance, and were willing to provide some commercial guarantees and Ameren was willing to make its Meredosia site available which reduced project costs because the turbine, condenser, heaters, switch gear, interconnect, structural steel, chimney and water intake equipment all were in place. DOE pulled funding from the project citing its failure to obligate the $1 billion by certain 2015 deadlines, and its inability to raise the balance of required capital.

The learning from these five projects can be summarized: None of the carbon capture systems envisioned in these projects are U.S.; large amounts of federal money could not overcome the risk tolerance of the sponsors or lenders; the only sponsor able to bring a project to completion was an independent power producer that had prior successful experience completing project developments and acquisitions.

Had only the Petra Nova, FutureGen and Summit projects been completed, the U.S. today would have three facilities, each capturing and using or sequestering carbon dioxide with substantial, valuable performance and cost data available to de-risk and improve subsequent projects. Undeniable, however, is the fact that none of those capture systems would have been U.S. and one of the power plants would have been entirely Japanese.

The U.S. is not in a position to lead the next generation of clean coal, and may be in jeopardy of falling further behind. Major vendors are in trouble: GE acquired Alstom, but is in the middle of a reorganization and recapitalization; B&W is in financial straits. Its 52-week share price high was $7.577. Its 52-week low was $0.33; Foster Wheeler has, for all intents, exited the U.S. The last major turnkey projects in the U.S. power market were the V.C. Summer and Vogtel nuclear power plants. Both are failed projects in terms of cost and schedule. One must ask whether the U.S. has lost its ability to construct large, complicated turnkey

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. James F. Wood

projects on time and on cost. China, meanwhile, is constructing 15 similar facilities; schedules and costs are reported to be on plan. (https://en.wikipedia.org/wiki/Nuclear_power_in_China); (http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx)

The investment and production tax credits afforded renewable generation have allowed owners to bid extremely low prices to the grid. This pushes fossil generation to the right on the dispatch curve. The coal generation fleet, in general, is no longer base-loaded. Cyclic operation adds maintenance expense to these units. On average, the coal fleet is 33% thermally efficient, whereas the newer gas fired combined cycle fleet is ~50% thermally efficient. Natural gas a carbon content is roughly 57% of bituminous coal. When the efficiency improvement is factored, natural gas produces 47% the amount of carbon emissions of coal per kWh.

Owners of coal-fired generation, and (carbon-free) nuclear generation say they are unable to compete with efficient natural gas combined-cycle generation, and tax advantaged renewables. In PJM, First Energy Solutions (First Energy's unregulated generation) announced the sale or retirement of substantial coal generation in Ohio, Pennsylvania and West Virginia (Pleasants in Belmont, WV- Although scheduled for closure in January 2019, the following statement was released in late 2018 by the WV Governor's office: "First Energy has notified the regional grid administrator, PJM, that it intends to keep the plant, that employs 160 people, operational until June 1, 2022,") , and announced the retirement of three nuclear plants. Many owners of coal fired generation have announced plans to become carbon-free, or carbon-neutral, by mid-century. So, in addition to a back seat in technology leadership, potential sponsors of demonstration projects have signaled a lack of interest in participating in the development of advanced clean coal technologies.

Questions from Senator Ron Wyden

Questions: During your testimony, you mentioned that West Virginia University was leading innovative research on the recovery of rare earth elements from coal wastes. I think the importance of this research is even more important, given the chaotic trade policy this Administration has pursued. Do you think market incentives and economics will be enough to encourage up-cycling these critical minerals?

Do you have suggestions for other actions legislators' can take to jumpstart lithium-ion disposal and recycling infrastructure to mitigate this risk?

Answer: There are substantial federal and private equity investment interests in the extraction of rare earth elements from coal wastes. West Virginia University (WVU) is developing extraction technologies under a Cooperative Agreement with The U.S. Department of Energy. The DOE's sponsorship has been a critical collaboration to move extraction technologies forward. WVU has a commitment with DOE to reach a mixed ore concentration of 2% from mine waste sources. Early testing at its facility in Morgantown suggests the mixed ore extraction concentrations will exceed this value. The higher the concentration of mixed rare earth oxides extracted from these wastes, the less expensive it will be to concentrate them further to commercially useful, high purity metals.

U.S. Senate Committee on Energy and Natural Resources
February 7, 2019 Hearing: *The Status and Outlook of Energy Innovation in the United States*
Questions for the Record Submitted to Mr. James F. Wood

Today, China is said to control 85%-90% of the world's supply of rare earths. With this much control, China is able to set prices and withhold supplies. It is critical that any competing technology be able to scale with a cost structure that can deal with China's price flexibility. Assuming WVU continues to produce these good results with a high degree of fidelity, the process economics will scale and private sector investment will be attracted.

WVU's research focuses on recovering rare earths from acid mine drainage, the biggest single pollutant in the eastern U.S. coal fields. Mine drainage must be partly, if not completely, remediated in order to recover rare earths. However, the Federal Clean Water Act, as currently interpreted, discourages voluntary remediation of acid mine drainage: 'If you touch it you own it-forever.'

Federal legislative guidance could be critical to moving this source of rare earth elements to market: For example, Good Samaritan provisions for rare earth production facilities to encourage both mine drainage remediation and rare earth recovery.

Ownership and control of the REE resource: Uncertain now, should be designated the property of the entity that is treating the mine drainage source. This would allow state agencies and private entities that wish to recover rare earths to proceed with the certainty that they will realize the benefits.

Designation as a Strategic/Critical Mineral Reserve. Price supports and/or tax incentives could be critical in buffering this fledgling industry from foreign market manipulation.

Lithium is not a rare earth in the same way as lanthanum, neodymium, ytterbium and the other 14 rare earths; it is the 25th most abundant element on the earth's crust and currently Chile has the largest lithium reserves at 7.5 million metric tons, compared to 3.2 million metric tons in China. But lithium's use in batteries is important, and the growth of electric vehicles (EV) using lithium titanate and lithium-iron-phosphate batteries in the EV powertrain should encourage thoughtful discussion now about recycling these batteries at end-of-life. It seems counterproductive to rely on EVs for emissions improvements and then to create very unhealthy waste streams that may be incinerated or landfilled.

Lead acid batteries are ubiquitous in gasoline powered cars, and are 99% recyclable. Private sector enterprises that establish lead acid battery recycling, often include recycling operations for rechargeable batteries that contain nickel cadmium (NiCad). In the same way renewable power generation receives tax credits, battery recyclers could receive credits based on throughput and types of recycling processes that might encourage the recyclers to offer residential and business pickup of batteries for recycling. Lastly, the U.S. DOE is the agency leading a research effort in lithium-ion battery recycling at Argonne National Laboratory: https://waste-management-world.com/a/doe-launches-uss-first-lithium-ion-battery-recycling-rd-center

IEEE★USA IEEE

February 11, 2019

To Whom It May Concern:

Re: Comments by IEEE-USA for the Senate Energy and Natural Resources Committee Hearing to Examine the Outlook of Energy Innovation in the United States

IEEE-USA would like to thank the Senate Energy and Natural Resources Committee for holding this important hearing. For nearly 50 years, the 180,000 engineers, researchers, and technical professionals represented by IEEE-USA have worked at the forefront of energy research and development to ensure that the United States has a secure, reliable, and efficient power supply. We applaud your leadership on this issue, and look forward to working with you to find creative and sustainable ways to address America's long-term energy needs

IEEE-USA recommends that the committee focus its attention on four challenges facing our energy system: securing cost effective power generation and utilization options, supporting the construction and maintenance of reliable and intelligent electric grid infrastructure, strengthening domestic energy security, and ensuring environmental stewardship of energy resources.

Securing Cost Effective Power Generation and Utilization Options

Investing in enhanced power generation systems will drive 21st century energy trends by providing lower cost energy to consumers while improving their access to energy resources. IEEE-USA urges Congress to support federal energy programs that improve power generation, transmission, and distribution in order to lower costs and improve reliability for American consumers. To accomplish this, Congress should invest in research and development programs in areas including energy storage and nuclear power generation.

Energy storage technology, including battery and thermal storage as well as flywheel and compressed air applications, has the potential to revolutionize America's power system. The ability to store large amounts of power would add flexibility and resilience to our grid, while making intermittent energy sources, including solar and wind, more viable. In addition to funding research, Congress should work with the federal agencies to amend regulatory policies to bridge the gap between federal regulation of the transmission grid and individual state regulation of electricity distribution.

Reliable, proven, safe and carbon-free nuclear energy needs to be a part of our energy portfolio. IEEE-USA recommends that Congress prioritize domestic nuclear power generation programs as a means to improve domestic energy generation. Nuclear power plants are cost competitive with fossil fuels and other renewable energy sources. Moreover, these plants provide large amounts of dependable electricity to offset the current variability of renewables. Most existing nuclear plants can safely operate for decades. IEEE-USA strongly recommends that Congress provide funding for further development of Small Modular Reactor technology while federal labs and industry continue developing advanced nuclear plant designs. Additionally, Congress should support advance nuclear fuel reprocessing technology and comprehensive nuclear fuel management programs to reduce the amount of waste produced by nuclear facilities and mitigate the risk of proliferation of nuclear fuels and materials.

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Supporting Construction of Reliable and Intelligent Electric Grid Infrastructure

Today's US electric grid is a network of approximately 10,000 power plants, 170,000 miles of high voltage transmission lines, more than six million miles of lower voltage distribution lines, and 15,000 substations. In order to improve the US electric grid infrastructure, IEEE-USA recommends support for federal grid research programs at our national labs and NIST's Smart Grid research programs as well as their development of Smart Grid Interoperability Standards.

In rural areas of the country, renewable energy sources are located far from population centers and transmission lines provide power to consumers. To help address the unique electricity needs of rural American communities, IEEE-USA recommends that Congress promote improved coordination between federal, state, and local governments to develop regional plans that expand the transmission system. This will allow improved transmission capacity that links natural gas plants, offshore and on-shore wind farms, solar energy plants, and other energy resources to customers. Power distribution must cross state lines and political boundaries. To be as effective as possible, the federal government must coordinate with local and state entities to ensure its efficiency and effectiveness.

America's transmission grid is under stress as electricity demand grows faster than supply. While this challenge requires expanded energy generation, Congress can reduce the amount of new generation needed by making our distribution system more efficient. Increased funding for research and development into emerging distribution technology at the DOE national labs is needed to realize these efficiencies and improve grid resilience and reliability.

Strengthening Energy Security
Recent events in Ukraine and elsewhere have demonstrated vulnerabilities in electric grid technology, and the enormous danger that hostile disruptions pose to our nation. Congress needs to act decisively to protect our nation from these threats. To improve our energy security, IEEE-USA urges Congress to support programs that improve integration of renewable energy resources into our energy portfolio, fund research and development in energy storage and nuclear fuel, support federal programs aimed at improving the cyber and physical security of our power and energy infrastructure, and enhance the integration of renewable energy resources into our energy grid.

IEEE-USA recommends that Congress aggressively support programs to improve the cyber and physical security of critical power and energy infrastructure. Threats from cyberspace to our electrical grid are rapidly increasing and evolving. Cyber connectivity has increased the efficiency and safety of our electrical generation and distribution systems, but it has also added complexity to the control systems. The DOE must increase R&D in areas to ensure the security of the algorithms, protocols, and chip-level and applications that support our electrical grid.

Because renewable energy generation facilities can be smaller and more widely distributed across the grid, they have the potential to improve grid reliability, strengthen our national and economic security and improve electricity distribution to consumers –if these resources are properly integrated into the grid. Increasing energy storage will similarly strengthen the resilience of our electrical grid. IEEE-USA strongly supports necessary investments in cybersecurity, R&D and standards development to protect our nation's grid.

Responsible Stewardship of Energy Resources

IEEE-USA recommends that Congress support programs that diversify our domestic portfolio to improve American energy resources while also protecting the environment. Specifically, we recommend expanding renewable electricity generation, reducing the environmental footprint of power systems where possible, and advancing research development programs.

America's long-term energy needs will be immense. The capture, transport, utilization and storage of carbon is an enormous infrastructure challenge. However, it is necessary that we consider each of these resources as part of the portfolio of available energy options.

Congress should invest in innovative research across the energy sector, including nuclear power, carbon capture and storage, energy efficiency and emerging energy technologies. We believe that there is a clear role for traditional power sources in our nation's power grid but also a role for renewables. Moreover, we promote the development of numerous technologies that are not yet viable but could prove invaluable to our nation in the future. We encourage Congress to pursue a balanced approach to energy production, one that considers our current energy needs and the needs of our environment.

Conclusion

Thank you for the opportunity to provide comments to the committee. We hope to be a resource to you as you move forward in developing the policies necessary to help build the next generation energy technology. We look forward to working with Congress to develop the most advanced power generation systems, increase energy storage capacity, improve carbon capture technology, and build nuclear power systems. America's energy needs are enormous, but so are our energy resources. Together with Congress, we hope to build the next generation energy systems to meet these challenges.

Feel free to contact IEEE-USA's Government Relations Staff, Aline McNaull, at a.mcnaull@ieee.org if we can be of further assistance.

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