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ENERGY INNOVATION: LETTING TECHNOLOGY LEAD

HEARING

BEFORE THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

FIRST SESSION

JULY 19, 2017

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July 19, 2017

ENERGY INNOVATION: LETTING TECHNOLOGY LEAD

Tuesday, July 19, 2017

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

The Committee met, pursuant to call, at 10:09 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Lamar Smith [Chairman of the Committee] presiding.

LAMAR S. SMITH, Texas
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas
RANKING MEMBER

Congress of the United States
House of Representatives

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
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Full Committee

Energy Innovation: Letting Technology Lead

Wednesday, July 19, 2017
10:00 a.m.
2318 Rayburn House Office Building

Witnesses

Dr. Jacob DeWitte, President and CEO, Oklo

Dr. Gaurav N. Sant, Associate Professor and Henry Samueli Fellow, Department of Civil and Environmental Engineering, Henry Samueli School of Engineering and Applied Science, University of California, Los Angeles (UCLA)

Dr. Venky Narayanamurti, Benjamin Peirce Research Professor of Technology and Public Policy, John A. Paulson School of Engineering and Applied Sciences, Harvard University

Mr. Kiran Kumaraswamy, Market Development Director, AES Energy Storage

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

HEARING CHARTER

July 12, 2017

TO: Members, Committee on Science, Space, and Technology

FROM: Majority Staff, Committee on Science, Space, and Technology

SUBJECT: Full committee hearing: "Energy Innovation: Letting Technology Lead"

The Committee on Science, Space, and Technology will hold a full committee hearing titled Energy Innovation: Letting Technology Lead on Wednesday, July 19, 2017, at 10:00 a.m. in Room 2318 of the Rayburn House Office Building.

Hearing Purpose:

The purpose of the hearing is to highlight private sector leadership on commercializing next generation energy technology to increase efficiency, environmental benefit, and consumer savings. This hearing will also explore the impact of research infrastructure and federally funded basic and early stage research on technology innovation, and regulatory hurdles that limit the success of innovative technologies.

Witness List

- **Dr. Jacob DeWitte,** *President and CEO, Oklo*
- **Dr. Gaurav N. Sant,** *Associate Professor and Henry Samueli Fellow, Department of Civil and Environmental Engineering, Henry Samueli School of Engineering and Applied Science, University of California, Los Angeles (UCLA)*
- **Dr. Venky Narayanamurti,** *Benjamin Peirce Research Professor of Technology and Public Policy, John A. Paulson School of Engineering and Applied Sciences, Harvard University*
- **Mr. Kiran Kumaraswamy**, *Market Development Director, AES Energy Storage*

Staff Contact

For questions related to the hearing, please contact Emily Domenech of the Majority Staff at 202-226-2179.

Chairman SMITH. The Committee on Science, Space, and Technology will come to order.

Without objection, the Chair is authorized to declare recesses of the Committee at any time.

And welcome to today's hearing titled "Energy Innovation: Letting Technology Lead." I'll recognize myself for an opening statement and then the Ranking Member for her opening statement.

Today we will hear from a panel of private sector innovators who are inventing the way to bring next-generation technology to the energy market. New technology provides solutions to today's energy and environmental challenges. Instead of government mandates, more regulations, and higher energy taxes, the federal government should invest in the research that allows innovative technology like advanced nuclear power and energy storage to succeed. We should all agree on these technology-driven energy solutions.

Unfortunately, nuclear power, which is the only reliable emissions-free source of electricity, is still criticized by environmental activists today. Those who are sincerely interested in solving some of America's environmental challenges should endorse and promote these critical new technologies.

This hearing will consider the value of federally funded basic and early-stage research as well as the research infrastructure at universities and national labs. These investments provide valuable expertise that would otherwise be unavailable to industry.

The Science Committee has jurisdiction over the $9 billion R&D portfolio at the Department of Energy, which funds basic science and energy research. Fundamental research conducted by the DOE Office of Science has led to groundbreaking discoveries about our universe, innovative new technologies, and private sector achievements across the energy and manufacturing industries.

Much of the technology we will hear about today is rooted in the basic science discoveries made at DOE national labs. Industry can build on these early-stage research discoveries, and use research infrastructure to create market-ready, next-generation energy technologies. For example, Dr. Jacob DeWitte, who started his career as an intern at Sandia National Lab, is the Co-Founder of Oklo, a privately funded startup company working to commercialize a small advanced nuclear reactor design. Dr. DeWitte's compact fast reactor design is ideal to replace the diesel generators used in rural areas, industrial operations, or even on military bases.

This reactor was developed using early-stage nuclear energy research conducted by DOE national labs. It will have zero emissions and could lower costs for consumers by up to 90 percent. If environmentalists are serious about reducing emissions, they should champion advanced nuclear reactors as an essential part of a clean energy future.

At UCLA, Dr. Gaurav Sant and his team have used basic research in chemistry, materials science, engineering, and high-performance computing to design a technology that converts carbon dioxide into a cement-like material. This technology could take captured carbon dioxide from power plants and turn it into a usable, cost-effective material. This innovative technology has the potential to revolutionize the market for CO_2, turning a waste product into profit.

Even large companies can benefit from basic research. AES Energy Storage is revolutionizing renewable energy through the deployment of batteries for the electric grid. AES's most recent project in California is capable of storing up to 120 megawatt hours of energy produced by wind and solar power. This is the energy equivalent of serving 20,000 customers for four hours. Basic and early-stage research in electrochemistry can improve the efficiency and resiliency of the thousands of batteries used in these facilities.

This Committee authorized exactly this kind of basic and fundamental research in the DOE Research and Innovation Act, which passed the House earlier this year. Enabling these private sector innovators to develop the most competitive ideas is essential to groundbreaking energy technology. If we want to protect the environment, lower costs for consumers, and increase our energy potential, innovative technology is the solution.

And note that during the White House Made in America week, we have three American companies testifying on innovative technology.

By allowing the market, not the government, to determine the best approach, we can develop technology that will increase energy efficiency, reduce environmental impact, and save the American people money.

America's energy history is full of innovative technologies that have unlocked new possibilities. It is technology, not regulation, that improves efficiency, lowers costs, and reduces the environmental impact of all kinds of energy.

For too long the government has picked winners and losers through regulation, federal loans and loan guarantees, or market-distorting subsidies. It is time to let the scientists, researchers, engineers, and inventors ensure that the United States remains the world technology leader and is better able to address environmental concerns.

As we shape the future of the Department, our priority must be basic energy research and development that only the federal government has the resources to pursue. This will allow private sector innovators, like the witnesses who join us today, to take groundbreaking energy technology to the marketplace, creating jobs and growing our economy.

[The prepared statement of Chairman Smith follows:]

COMMITTEE ON
SCIENCE, SPACE, & TECHNOLOGY
Lamar Smith, Chairman

For Immediate Release
July 19, 2017

Media Contact: Kristina Baum
(202) 225-6371

Statement of Chairman Lamar Smith (R-Texas)
Energy Innovation: Letting Technology Lead

Chairman Smith: Good morning. Today we will hear from a panel of private sector innovators who are inventing the way to bring next generation technology to the energy market.

New technology provides solutions to today's energy and environmental challenges. Instead of government mandates, more regulations, and higher energy taxes, the federal government should invest in the research that allows innovative technology like advanced nuclear power and energy storage to succeed. We should all agree on these technology-driven energy solutions.

Unfortunately, nuclear power, which is the only baseload, emissions free source of electricity, is still criticized by environmental activists today.

If those on the left are truly interested in solving some of America's environmental challenges, they would endorse and promote these critical new technologies.

This hearing will consider the value of federally funded basic and early stage research as well as the research infrastructure at universities and national labs. These investments provide valuable expertise that would otherwise be unavailable to industry.

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For example, our witness Dr. Jacob DeWitte, who started his career as an intern at Sandia National Lab, is the co-founder of Oklo, a privately funded start-up company working to commercialize a small advanced nuclear reactor design.

Dr. DeWitte's compact fast reactor design is ideal to replace the diesel generators used in rural areas, industrial operations, or even on military bases. This reactor was developed using early stage nuclear energy research conducted by DOE national labs.

It will have zero emissions and could lower costs for consumers by up to 90%. If environmentalists are serious about reducing emissions, they should champion advanced nuclear reactors as a key part of a clean energy future.

At UCLA, Dr. Gaurav Sant and his team have used basic research in chemistry, materials science, engineering, and high performance computing to design a technology that converts carbon dioxide into a cement-like material.

This technology could take captured carbon dioxide from power plants and turn it into a usable, cost effective material. This innovative technology has the potential to revolutionize the market for CO2, turning a waste product into profit.

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As we shape the future of the Department, our priority must be basic energy research and development that only the federal government has the resources to pursue. This will allow private sector innovators, like the witnesses who join us today, to take ground-breaking energy technology to the marketplace, creating jobs and growing our economy.

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Chairman SMITH. That concludes my opening statement, and the gentlewoman from Texas, the Ranking Member, is recognized for hers.

Ms. JOHNSON. Thank you very much, Mr. Chairman, and thank you for holding this hearing. I'd like to thank all of our witnesses for being here today.

In years past, this Committee would hold an annual hearing on the Administration's budget proposal for the Department of Energy, and I would typically begin my remarks with a few brief reminders of how government-supported energy research can pay off, ranging from the birth of the nuclear power industry to the shale gas revolution. I'd then move on to provide my views on what usually was a thoughtful, well-crafted budget proposal, even if I might have had some disagreements with it.

Unfortunately, this is not a typical year. First, while the Administration's budget blueprint was released back in March and its detailed budget request was released in May, our Committee has still not yet scheduled a hearing with Secretary Perry testifying to explain and defend his proposal.

While the panel before us today has a broad and impressive range of expertise that will at least enable us to begin this discussion, none of these witnesses can speak for the Department. In order for this Committee to fulfill its oversight responsibilities, I urge the Chairman to schedule a hearing with the Secretary as soon as possible.

As for the fiscal year DOE budget request, I want to be clear: I am deeply disturbed by the Trump Administration's proposed budget for the Department of Energy. It would completely eliminate ARPA–E, an agency that has already demonstrated incredible success in advancing high-risk, high-reward energy technology solutions that neither the public nor the private sector had been willing or able to support in the past. This accomplishment was highlighted in a congressionally mandated National Academies review of the agency released just last month. Bipartisan industry leaders like Norm Augustine and Bill Gates have repeatedly called for tripling this agency's budget given the unique role that it is now playing in our energy innovation pipeline.

And I'd be remiss if I didn't refer my colleagues to Secretary Perry's March 8th tweet, issued just eight days before the budget blueprint was released, which states, and I quote, "Innovators like the ones supported by our ARPA–E program are key to advancing America's energy economy." I really couldn't have said it any better.

In addition, the President's budget proposal would eliminate DOE's loan guarantee and Advanced Vehicle Technology Manufacturing programs. Mr. Chairman, we just held a hearing on these programs a few months ago, and we learned that their record of accomplishment more than justifies our continued support. The DOE Loan Programs Office has been instrumental in launching the utility-scale PV industry, Tesla Motors, the construction of our first new nuclear reactors in 30 years, and it is now supporting the commercialization of new carbon capture and reuse technologies. Overall, the Loan Office's losses are only about two percent of its entire portfolio, a rate that is lower than many venture capitalists achieve. And even after accounting for those losses, the interest payments from these loans and loan guarantees have returned over $1 billion to the Treasury. If we're aiming to create jobs and reduce the deficit, these are exactly the programs we should be supporting.

Finally, the budget proposal would slash the Department's other critical energy technology offices for energy efficiency, renewables, the grid, fossil energy, and nuclear energy by $2.3 billion overall, or about 57 percent. And it would cut the DOE Office of Science, the largest supporter of physical sciences research in the country, by over $900 million, or 17 percent.

Our national infrastructure for scientific and energy research would be irreparably harmed if these cuts were actually implemented.

Now, I'm not going to tell you that every program the Department currently implements is perfect, that reforms should never be considered, or that reasonable people can't simply disagree on the best way to allocate its resources even after a careful, rigorous review.

One of my largest concerns now, especially given the incredibly severe damage that this proposal would impose on our entire research enterprise, is that such a thoughtful review never actually took place before this budget proposal was released. In fact, last month Administration officials confirmed that there was no engagement with the private sector at all to determine what industry would be able or willing to fund in the absence of federal investment. This is simply unacceptable.

In closing, I hope that we can all take a step back and more carefully consider the direction we want to move the Department in over the next several years.

I look forward to the hearing and listening to our witnesses on all of these critical issues. I yield back whatever balance of time I have.

[The prepared statement of Ms. Johnson follows:]

OPENING STATEMENT
Ranking Member Eddie Bernice Johnson (D-TX)

House Committee on Science, Space, and Technology
"Energy Innovation: Letting Technology Lead"
July 19, 2017

Thank you, Chairman Smith for holding this hearing, and I would like to thank the witnesses for being here today.

In years past, this Committee would hold an annual hearing on the Administration's budget proposal for the Department of Energy, and I would typically begin my remarks with a few brief reminders of how government-supported energy research can pay off – ranging from the birth of the nuclear power industry to the shale gas revolution. I'd then move on to provide my views on what usually was a thoughtful, well-crafted budget proposal, even if I might have had a few disagreements with it.

Unfortunately, this is not a typical year. First, while the Administration's budget blueprint was released back in March and its detailed budget request was released in May, our Committee has still not yet scheduled a hearing with Secretary Perry testifying to explain and defend his proposal. While the panel before us today has a broad and impressive range of expertise that will at least enable us to begin this discussion, none of these witnesses can speak for the Department. In order for this Committee to fulfill its oversight responsibilities, I urge the Chairman to schedule a hearing with the Secretary as soon as possible.

As for the FY18 DOE budget request, I want to be clear. I am deeply disturbed by the Trump Administration's proposed budget for the Department of Energy. It would completely eliminate ARPA-E, an agency that has already demonstrated incredible success in advancing high-risk, high-reward energy technology solutions that neither the public nor the private sector had been willing or able to support in the past. This accomplishment was highlighted in a Congressionally mandated National Academies review of the agency released just last month. Bipartisan industry leaders like Norm Augustine and Bill Gates have repeatedly called for tripling this agency's budget given the unique role that it is now playing in our energy innovation pipeline. And I'd be remiss if I didn't refer my colleagues to Secretary Perry's March 8th tweet, issued just 8 days before this budget blueprint was released, which states, and I quote, "Innovators like the ones supported by our ARPA-E program are key to advancing America's energy economy." I couldn't have said it better myself.

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Now, I am not going to tell you that every program the Department currently implements is perfect, that reforms should never be considered, or that reasonable people can't simply disagree on the best way to allocate its resources even after a careful, rigorous review. One of my largest concerns now, especially given the incredibly severe damage that this proposal would impose on our entire research enterprise, is that such a thoughtful review never actually took place before this budget proposal was released. In fact, last month Administration officials confirmed that there was no engagement with the private sector at all to determine what industry would be able or willing to fund in the absence of federal investment. That is simply unacceptable.

In closing, I hope that we can all take a step back and more carefully consider the direction we want to move the Department in over the next several years. I look forward to hearing what our witnesses have to say on each of these critical issues, and I yield back the balance of my time.

Chairman SMITH. Well, actually there's not much balance left but I appreciate the gentlewoman yielding back, and thank you for your statement.

Before I introduce our witnesses today, I'd like to introduce the newest member of the Science Committee, Ralph Norman of South Carolina. Having served as a former state rep in South Carolina, he brings a wealth of experience to the Committee, and he's going to be serving on the Environment and Oversight Subcommittees, and Ralph, we welcome you to the Committee.

And I'll go to our witnesses. Our first witness today is Dr. Jacob DeWitte, Co-Founder and CEO of Oklo. Previously, Dr. DeWitte worked at Sandia National Lab, Urenco U.S., and the Naval Reactor Research Laboratories. He studied nuclear engineering at the University of Florida and received his Ph.D. in nuclear engineering from MIT.

Our next witness is Dr. Gaurav N. Sant, Associate Professor and Henry Samueli Fellow in the Department of Civil and Environmental Engineering at the University of California, Los Angeles. Dr. Sant received his bachelor's degree, master's degree and Ph.D. from Purdue University.

Our third witness today is Dr. Venky, and he prefers to be called by his first name, Dr. Venky, which makes it easier on all of us. Dr. Venky is the Benjamin Peirce Research Professor of Technology and Public Policy at Harvard's John A. Paulson School of Engineering and Applied Sciences. Dr. Venky previously served as Dean of the John Paulson School of Engineering and Applied Sciences, and Dean of Physical Sciences at Harvard. He received his bachelor's and master's degree in physics from St. Stephen's College, Delhi University.

Our final witness today is Dr. Kiran Kumaraswamy, Market Development Director at AES Energy Storage. He previously served as the Senior Manager at ICF International in Fairfax, Virginia. He received his bachelor's degree in electrical engineering from the University of Madras.

Mr. KUMARASWAMY. Madras.

Chairman SMITH. Madras, and his master's degree in engineering from the University of Wisconsin, Madison.

And we welcome you all to the Committee hearing today and look forward to your testimony, and Dr. DeWitte, we'll begin with you.

TESTIMONY OF DR. JACOB DEWITTE, PRESIDENT AND CEO, OKLO

Dr. DEWITTE. Thank you, and Chairman Smith and Ranking Member Johnson, and distinguished Members of this Committee, I want to thank you for holding this hearing and for giving me the opportunity to testify today. I am honored to be here, and I'm eager to share my experience commercializing advanced reactor technologies that build upon a rich legacy of research and development with the national laboratory system and the Department of Energy.

As Chairman Smith mentioned in his intro, I was fortunate to grow up around Sandia National Laboratory, which played a huge role in influencing my decision to go into the fields of technology, science, engineering and math as well as pursue ultimately an entrepreneurial career, and I'm also excited to be working with them now further to commercialize this technology.

So I am the Co-Founder and CEO of Oklo, a Silicon Valley-based company developing and building a very small advanced reactor that produces 1 to 2 megawatts of electric power. We sometimes refer to this as a micro-reactor that is designed to bring distributed, clean, affordable, and reliable nuclear power in small packages to a wide variety of markets, both domestically and internationally.

We started Oklo because we believe advanced reactors will play a significant role in the energy mix of the future, and we want to make that future a reality as quickly as possible.

Over half of the active advanced reactor commercialization efforts ongoing in the United States today are pursuing fast reactor technologies. One of the key technologies to the success of fast reactor R&D in the United States has been the development of metal fuels. Metal fuels are alloys of uranium or other actinides that combine incredible durability, flexibility and resilience to achieve phenomenal fuel utilization, manufacturability, and safety performance. Metal fuel was used in several key early experimental reactors operated in the 1950s and 1960s and showed great promise but it was sidelined until several key engineering discoveries were made through R&D campaigns sponsored by the Atomic Energy Commission and then the DOE, which ultimately enabled the fuels to realize their potential. These advances were highlighted by successful demonstrations at the EBR–II reactor, which operated in Idaho.

Over half of the fast reactor developers in the United States are building upon this rich R&D legacy in metal fuel, and it is a striking example of a successful government investment in R&D that matured a promising technology to the point of readiness and commercialization.

There are also opportunities to expand upon the successes in metal fuel. Lessons learned in the development of metal fuels have identified avenues to expand its capabilities, which illustrates the continuum of innovation that can occur when one discovery leads to many more than can further advance the state of the art.

At Oklo, we are working to commercialize a reactor that builds on the successful legacy of metal fuel. We pursue a business model of following market needs and demands, in other words, we strive to make reactors people want. It can be tempting to push an exciting new technology to market, but then miss what the market needs for the sake of the technology, so talking to users to understand what the market requires and wants takes discipline. In our experience, we found the capabilities offered by metal fuel match customer needs and have continued to find market fit and traction thanks in part to R&D success of metal fuel.

We've partnered with several national labs to date including Argonne, Idaho and Sandia National Laboratories to support our commercialization work. A significant amount of this work has focused on commercializing our specific application and design of metal fuel. For example, we are working with Argonne and Idaho supported by the Gateway for Accelerated Innovation and Nuclear, also known as GAIN, to assemble fuel performance data that we used in formal pre-application meetings with the NRC to support our licensing case, as well as to fabricate three prototypic fuel elements demonstrating key characteristics, which we were excited to announce all three hit production specs.

We are currently expanding our work with the national labs because many of the capabilities we need are uniquely found in the national lab complex, providing us with an international advantage. This is why it is so important to maintain and preserve our capabilities and expertise in the national lab system and also why we need to develop new capabilities like a fast test reactor.

In fact, I would like to highlight the efforts to build a fast reactor that this Committee and Congressman Weaver has so earnestly led and supported in a bipartisan way. This is incredibly important to develop this capability in the United States because the construction and operation of a domestic fast test reactor will pay substantial dividends to American energy competitiveness as well as leadership. This facility will be a national asset and will not only accelerate ongoing advanced reactor commercialization efforts but will also be a catalyst for new innovations and new technologies.

Furthermore, to support ongoing innovation, DOE needs to provide a fuel source for demonstration, prototype, and first-of-a-kind advanced reactors by providing low enriched uranium fuels that are enriched above the five percent enrichment that current LWR fuels use.

In general, the regulatory challenges that we face in advanced reactor space have been overstated, and I'd like to take a few minutes, or few moments, I should say, to comment on that. While there are challenges, I must emphasize that the widely-held view that advanced reactors cannot be licensed today is mistaken. We are formally engaged in pre-application activities with the NRC and have found clear licensing pathways for our technology but work remains.

Innovation in nuclear is proceeding at a pace reminiscent of the early days of nuclear power, and the United States is still the global leader, but we need to be mindful of international competition. China and Russia are investing heavily to develop advanced nuclear technologies, and we cannot afford to fall behind. Our national capacity to innovate, combined with our national capabilities to research and develop, give us tremendous advantages.

Thank you.

[The prepared statement of Dr. DeWitte follows:]

Testimony of
Dr. Jacob DeWitte
CEO and Co-Founder, Oklo Inc.
Chair, Fast Reactor Working Group

Before the Committee on Science, Space, and Technology
United States House of Representatives

Energy Innovation: Letting Technology Lead

July 19, 2017

Written Testimony

Chairman Smith, Ranking Member Johnson, and distinguished members of this Committee, I want to thank you for holding this hearing and for giving me the opportunity to testify. I am honored to be here today, and I am eager to share my experience commercializing advanced reactor technologies that build upon a rich legacy of research and development with the national laboratory system and the Department of Energy.

I am the Co-Founder and CEO of Oklo, a Silicon Valley based company developing and building a very small advanced reactor that produces 2 MW of electric power. We sometimes refer to it as a micro-reactor that is designed to bring distributed, clean, affordable, and reliable nuclear power in small packages to the market. These reactors fit into a containerized system that can power a wide variety of markets both domestically and internationally, which do not have access to affordable and reliable power, and in some cases, do not have access to power at all.

Our reactor operates purely on natural forces, with very few moving parts in the entire system, and it is designed to operate for more than 10 years before refueling. It will produce reliable, affordable, safe, emission-free power wherever needed. The reactor is sized appropriately to open up new opportunities for clean and safe nuclear power in remote and rural communities, as well as industrial and military sites in areas that are too small for larger reactors. The Oklo reactor has the potential to reduce some of these customer's energy bills by up to 90 percent.

Furthermore, our reactor can use fuel nearly 300 times more efficiently than current reactors, producing less waste, and can actually consume the used fuel from today's reactors as well as the depleted uranium stockpiles around the nation. In fact, fast reactors like ours could power the world for over 500 years with the global inventory of used fuel and depleted uranium. Our reactors can also assist with plutonium disposition by consuming excess cold war era materials and turning them into clean, peaceful energy.

We started Oklo because we believe advanced reactors will play a significant role in the energy mix of the future, and we want to make that future a reality as quickly as we can.

Advanced Reactors

Advanced reactors are next generation nuclear technologies that can provide affordable, reliable, and clean power that can be deployed on a global scale. They offer the potential to realize the energy future envisioned by the intellectual giants upon whose shoulders we all stand: Fermi, Weinberg, Wigner, Seaborg, and others who saw the potential that next-generation reactors have. Some of the key attributes include:

- Competitive economics due to reduced capital costs and shortened construction times
- Multiple energy product streams ranging from electricity to process heat
- Improved fuel efficiency and the ability to consume used nuclear fuel
- Flexible operations such as load following and grid stabilization to couple with solar and wind
- Flexible siting, independent of access to cooling water

Advanced reactor technologies are varied and diverse in terms of the coolants, materials, fuels, and neutron spectrum they use, and fast reactors represent over half of the active advanced reactor commercialization efforts ongoing in the United States today. Fast reactors are well suited to achieving the benefits offered by advanced reactors, and they build upon a rich legacy of proven and demonstrated technologies, including the groundbreaking success of the EBR-II reactor.

Metal Fuels

One of the key technologies to the success of fast reactor research and development in the United States has been the development of metal fuels. Metal fuels are alloys of uranium or other actinides that combine incredible durability, flexibility, and resilience to achieve phenomenal fuel utilization, manufacturability, and safety behavior. Metal fuel was used in several early experimental reactors operated in the 1950s and 1960s, and showed great promise, but were sidelined until several key engineering discoveries were made through research and development campaigns sponsored by the Atomic Energy Commission (AEC) and then the Department of Energy (DOE) that enabled the fuels to realize their potential. These advances were highlighted by several successful demonstrations at the EBR-II reactor in Idaho which operated from 1964 to 1994:

- Demonstrated fuel recycling by using over 39,000 recycled fuel elements.
- Demonstrated high fuel utilization with less waste, achieving burnups four times higher than the current industry standard.

- Demonstrated groundbreaking safety behavior with the Shutdown Heat Removal Tests in 1986.

The benefits and capabilities of metal fuels make them a key enabling technology for advanced reactor developers, and over half of the fast reactor developers in the United States are building upon this rich research and development legacy. This is a striking example of a successful government investment in research and development that matured a promising early stage technology to the point of commercial readiness.

There are also opportunities to expand upon these successes. Lessons learned in the development of metal fuels have identified avenues to expand its capabilities and applicability to new designs and new performance features, such as advanced fabrication methods, liners and coatings, dopants, new claddings, new geometries, and tailored engineered properties at the atomistic level. These branches on the metal fuel tree may lead to higher temperature operations, longer fuel lifetimes, and overall better performance that further enhance the performance of fast reactors.

These technologies present research and development opportunities that can follow similar pathways, and are ripe for further investment as they mature to commercial readiness. In fact, industry is already partnering with the national laboratories to pursue some of these technologies. This illustrates the continuum of innovation that occurs when one discovery leads to many more that can further advance the state of the art.

Oklo is working to commercialize a reactor that builds on the successful legacy of metal fuel. We pursue a business model of following market needs and demands, in other words, we strive to make reactors people want. It can be tempting to push an exciting new technology to market, but miss what the market needs for the sake of the technology, so talking to users to understand what the market wants requires discipline. In our early days, we found the capabilities offered by metal fuel reactor designs fit customer needs, and have continued to find market fit and traction thanks in part to the research and development efforts in metal fuel.

Research Infrastructure

The research and development infrastructure at the national labs has played, and will continue to play a key role in commercializing advanced reactors. This infrastructure includes world-leading experimental facilities, research reactors, and expertise. These resources are also helpful to industry as we work with the national laboratories to tap into their capabilities.

We have partnered with several national labs to date, including Argonne National Laboratory, Idaho National Laboratory, and Sandia National Laboratories to support our commercialization efforts. A significant amount of this work has focused on commercializing our metal fuel design. For example, ongoing work with Argonne and Idaho supported by the Gateway for Accelerating

Innovation in Nuclear (GAIN) program has assembled fuel performance data that we used in formal pre-application meetings with the Nuclear Regulatory Commission (NRC) to support our licensing efforts, and has enabled us to fabricate three prototypic fuel elements demonstrating key manufacturability characteristics. We are currently expanding our work with the national labs because many of the capabilities we need are uniquely found in the national lab complex, providing us with an international advantage. Similar stories are found throughout the national lab system and are an example of how valuable the national lab system is.

Furthermore, I was fortunate to grow up near Sandia, and my experiences with the lab in my community were instrumental in my growth. Laboratory tours, staff visits to my schools, and internships I had at the lab were significant influences in my decisions to pursue technical work. The labs play a crucial role in their communities and the national innovation ecosystem.

Research and Development Challenges and Opportunities

The legacy of research and development by the DOE and its predecessors in the last 70 years has been tremendously helpful to advanced reactor developers today. We are all building on that work. More recently, DOE has supported programs to help accelerate advanced reactor commercialization by improving how industry can work with the national labs, but there is still more we can do. The GAIN program is a great example of recent efforts to enhance how industry can work with the national labs and DOE. In the past year, significant progress has been made through the GAIN program to advance these efforts, and these will continue to expand.

The work by DOE and the national labs to characterize and qualify advanced reactor fuels has been and will continue to be quite valuable to advanced reactor commercialization efforts. The facilities and resources used for this work are good examples of just some of the capabilities within the national laboratory complex from which we and other advanced reactor developers can benefit. GAIN provides an avenue for streamlined access to DOE facilities and expertise, and continued initiatives within the GAIN program will help propel advanced reactor efforts. Additionally, DOE sites could be ideal proving grounds for first-of-a-kind reactors. NuScale and INL are paving the way here, as NuScale plans to build their first plant in Idaho.

Unfortunately, some of these capabilities are also deteriorating, or have been shut down. For example, the premature closures of the FFTF and EBR-II reactors ended access to domestic fast neutron sources. This has slowed advanced reactor commercialization efforts, and has slowed the continuum of innovation that will lead to even better materials, fuels, and other technologies which will enhance advanced reactor capabilities in the future. These national assets and capabilities must be maintained.

New capabilities also need to be developed. I specifically want to highlight the efforts to build a fast test reactor that this Committee has so earnestly supported. It is a tragedy that we terminated our fast neutron irradiation capabilities in the 1990s, and are now forced to go overseas for irradiation testing. The lack of these domestic capabilities must be addressed, and the construction and operation of a domestic fast test reactor will pay substantial dividends to American energy competitiveness and leadership. This facility be a national asset that will not only accelerate ongoing advanced reactor commercialization efforts, but will also be the catalyst for new innovations and new technologies.

In addition to experimental facilities, DOE and the national labs are developing world leading modeling and simulation tools that support advanced reactor design and analysis. Advances in software and computing have helped fuel the recent growth of the advanced reactor industry. It has never been cheaper to design and analyze new technologies. These capabilities provide a significant advantage to U.S. advanced reactor developers, and we should invest in further research and development to enhance these capabilities and create new ones. However, it can be prohibitively difficult, costly, and time consuming for industry to access and use some of these publicly-funded capabilities. This can drive industry users away from these tools, limiting opportunities for commercialization and diminishing the value of the investments made to develop them. The challenges to accessing these tools are a result of a variety of factors, but one of which is the lack of minimal support to maintain these tools. Without maintenance, these tools will remain difficult to access and atrophy away. Fortunately, there has been demonstrable progress to improve these processes in the last year, but there is still more to do.

Other DOE resources and capabilities that are often underappreciated include their inventory of nuclear fuel materials, and their capability to provide these materials to support advanced reactor demonstrations. Demonstration, prototype, and first-of-a-kind advanced reactors will require a variety of fuels, and we will all benefit from being able to use some of the fuel that DOE manages. This is particularly relevant to low enriched uranium fuels that are enriched above the 5% enrichment that current light water reactor (LWR) fuels use. DOE should anticipate these opportunities, and manage their fuel resources accordingly to maintain fuels in usable forms and compositions. This will also reduce DOE's fuel management burdens.

DOE should also work with the relevant federal agencies to modernize nuclear export control rules. Unfortunately, recent changes to nuclear technology export controls are hindering innovation, and will handicap our global leadership. This is particularly important now so that the growing advanced reactor industry can flourish.

Finally, I must encourage federal agencies to be cautious with development or demonstration investments to avoid ones that are out of touch with the market. Unfortunately, these investments can follow "pet project" preferences or projects with strong lobby support, instead of following the market, which could severely damage the rising advanced reactor movement by sending false and incorrect market signals. We all have a vector on getting to market and achieving cost competitiveness, while producing emission-free power at a global scale. Getting there will be hard, but this is one of the most promising times for nuclear since the birth of the industry.

Regulatory Challenges and Opportunities

In general, the regulatory challenges to advanced reactor commercialization efforts have been overstated. While there are challenges, I must emphasize that the widely-held view that advanced reactors cannot be licensed today is mistaken. We are formally engaged in pre-application activities with the NRC and we have found clear licensing pathways for our technology. However, there is room for improvement and modernization.

Recent progress made by the NRC to support advanced reactor licensing is yielding value. The DOE's work to develop advanced reactor design criteria and other issues will have a substantial effect on advanced reactor licensing. Furthermore, recent NRC initiatives to use a core team review approach and safety focused reviews will improve cost and schedule predictability.

I also encourage updating security and staffing requirements so they are "right-sized" to reactor size and type. Furthermore, future regulatory reforms should yield requirements and cost burdens that reflect reactor size and safety performance. I would also like to acknowledge the work NuScale has done to address many of the challenges that advanced reactor developers face. The work they have done has helped pave the way on many issues, and we hope to build on this trend and pave the way forward for advanced reactor commercialization.

Closing Thoughts

Advanced reactor development has grown significantly in the past decade, particularly in the last five years, and these efforts are better equipped than ever to bring these technologies to market. Advances in computational modeling and simulation, along with an injection of talented, creative, and hungry young engineers into the nuclear industry have fueled much of this growth. Federal efforts to attract students into nuclear engineering programs over the last decade are paying dividends, and there is more to come. Furthermore, advanced reactor research and development activities sponsored by the DOE and the national laboratories over the past few decades have demonstrated some of the core technologies that many of these startups and larger companies are working to commercialize.

Innovation in nuclear is proceeding at a pace reminiscent of the early days of nuclear power, with dozens of startups and over $1 billion in private capital at work developing the future of energy technologies. The United States is still the global leader in nuclear technology, and we have taken steps to cultivate this growing movement, but there is still more to be done to remove outdated obstacles, and overcome hurdles that slow the growth of this industry. Furthermore, we must be mindful of international competition. China and Russia are investing heavily to develop advanced nuclear technologies, and we cannot afford to fall behind. Our national capacity to innovate, combined with our national capabilities to research and develop give us tremendous advantages. We have a unique opportunity in front of us. If we seize it, we can lead the world in a clean energy transition powered by advanced reactors that can mitigate the effects of climate change, bring affordable, reliable, emission-free energy to the billions without it, and support the growth of an entirely new technology and manufacturing workforce. Furthermore, these technologies can fuel mankind's ambitions of navigating the stars. We need energy to explore the heavens, and nuclear energy will power future trips to our neighboring planets and beyond. I thank you for this opportunity to testify, and would be pleased to respond to any questions you might have today or in the future.

Jacob DeWitte Biography

Jacob DeWitte is the co-founder and CEO of Oklo, a Sunnyvale, CA based company developing and building small nuclear reactors. Jacob has been working with nuclear technology since his childhood, and has deep experience with nuclear reactor design and analysis. He has worked with many advanced reactor designs including sodium fast reactors, molten salt reactors, and next-generation PWRs. Jacob has also been involved with front-end and back-end nuclear fuel cycle technology development and analysis. Jacob worked on the reactor design efforts on a waste consuming molten salt reactor at the University of Florida, as well as the core design at GE for their PRISM sodium cooled fast reactor. Jacob also has experience working with experimental irradiation testing facilities during his time at Sandia National Labs where he was able to work with a fast pulse reactor. Jacob has also worked on nuclear facility licensing and early stage procurement during his time at Urenco US. Jacob is originally from Albuquerque, NM. He earned his BS in nuclear engineering from the University of Florida and his SM and PhD in nuclear engineering at MIT.

Chairman SMITH. Thank you, Dr. DeWitte.
And Dr. Sant.

TESTIMONY OF DR. GAURAV N. SANT, ASSOCIATE PROFESSOR AND HENRY SAMUELI FELLOW, DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING, HENRY SAMUELI SCHOOL OF ENGINEERING AND APPLIED SCIENCE, UNIVERSITY OF CALIFORNIA, LOS ANGELES (UCLA)

Mr. SANT. Thank you, Chairman Smith, Ranking Member Johnson, and Members of the Committee for inviting me to appear before you as you review private sector leadership in next-generation energy technology to increase efficiency, environmental benefits and consumer savings, and review associated research and regulatory hurdles.

As requested by the Committee, I am focusing my testimony on research that we've been engaged in that seeks to convert carbon dioxide (CO_2) into a novel building material, CO_2NCRETE, with CO_2 at the front. The views expressed herein are my own, and do not necessarily represent those of UCLA. In brief, I'm an Associate Professor and Henry Samueli Fellow in the Henry Samueli School of Engineering and Applied Science at the University of California, Los Angeles. I'm a civil engineer, and a materials scientist with broad ranging expertise in materials synthesis, characterization and simulation.

My testimony today can be summarized as follows starting with the motivation. Electricity generation from coal-fired power plants alone represents about 25 percent of CO_2 emissions from the United States. It's about 1.2 billion tons of CO_2 emitted in 2016. Carbon capture and storage (CCS) has been proposed as a solution to mitigate CO_2 emissions caused by industrial activities. However, CCS is not always viable due to issues with high cost, uncertainty in the permanence of the sequestration solution, and/or the lack of suitable geological features in the local vicinity where CCS can be achieved. Therefore, it is necessary to identify and create new pathways for the beneficial utilization of CO_2 while simultaneously yielding a permanent CCS solution.

A novel approach to mitigate CO_2 emissions is by upcycling or beneficially utilizing industrial wastes that may be in the form of solids, liquids, or vapors to create new materials, for example, CO_2NCRETE. As an example, in the case of flue gas-borne CO_2, this is accomplished by converting gas borne CO_2 by mineralization into stable carbonate compounds which may offer cementitious character into building materials. Not only do such innovative technologies yield environmental benefits, but they also have the potential to reduce the environmental impact of the construction sector as follows. The production of ordinary Portland cement—the primary binding agent used in traditional concrete—results in nearly nine percent of global CO_2 emissions. For example, nearly .9 tons of carbon dioxide are emitted per ton of OPC produced. Therefore, the development of new cementation agents that take up CO_2 will help reduce the CO_2 emissions associated with OPC and concrete) production.

With respect to material recycling, the simultaneous reuse of CO_2 and industrial byproducts—solid wastes—resulting from coal combustion creates a new paradigm in waste-to-resource recycling of materials. This creates a circular economy paradigm between the energy and construction sectors and thus greatly enhances the sustainability metrics of both industries. The upcycling process that we've proposed and demonstrated is accomplished by contacting calcium hydroxide with flue gas-borne CO_2. Such calcium hydroxide or portlandite can be secured by calcining limestone and hydrating the lime that results or by leaching calcium species from alkaline industrial wastes such as slags and coal combustion residuals. Following combination with fine and coarse mineral aggregates, chemical additives, water, and suitable binding agents if needed—similar to traditional concrete—this mixture containing calcium hydroxide forms a slurry that can be shaped into common construction elements, such as beams, columns, and slabs. Importantly, the upcycled concrete production process is designed to bolt-on to large point-source CO_2 emitters including petrochemical facilities, coal- and natural gas-fired power plants, and cement plants. In each case, emitted flue gas is used to both provide both waste heat to hasten chemical reactions, and to provide CO_2 to ensure mineralization without imposing any additional need for emissions control. The process cycle is being designed for scalable operations to accelerate the R&D pathway towards pilot-scale trials, technology commercialization and deployment.

CO_2NCRETE offers a transformative route for the beneficial utilization of flue gas-borne CO_2 in the cementation cycle. This creates pathways to produce construction materials with up to 50 percent or lower carbon dioxide intensity than ordinary Portland cement.

Furthermore, by creating a robust CO_2 and solid waste offtake partnership between the energy and the construction sectors, the outcomes of this work create new sectoral synergies which would be difficult to realize otherwise. Significantly, this CO_2 upcycling approach can reduce the environmental impact of electricity generation from fossil fuels, while simultaneously advancing the materials, methods and processes utilized by the construction sector.

Financial support secured from federal agencies including the Department of Energy, the Department of Transportation, and the National Science Foundation has been instrumental in enabling our work. The support of federal agencies such as those noted above, and others, is critical for enabling basic and applied R&D, technology creation and development. Broadly, with significant competitive international investments in R&D around the world, federal support of basic and applied R&D, in core and emerging domains such as CO_2 utilization and reuse is more important now than ever. This is because federal R&D support is vital to enable the creation of knowledge and technology within universities and national laboratories, the reservoirs of knowledge that have ensured U.S. intellectual leadership globally.

Furthermore, federal support of R&D is especially important in the case of technologies which benefit conventional industries which are unlikely to being offshored, for example, electricity generation and the construction sector, which feature reduced appetite for technical and commercial risk due to uncertainty in revenue, profit pressures, regulatory and compliance burdens, or high costs associated with the development of greenfield facilities with long operating horizons. Therefore, it becomes necessary for the government to underwrite a larger proportion of the costs associated with R&D that has the potential to benefit such industries, and in turn, the general public, until sufficient technology maturity is achieved.

However, once such maturity is achieved, and industry is assured of the commercial value and potential of new technology, it is expected that industry will take over and accelerate the residual R&D pathway including commercial trials that results in market penetration, and diffusion of new technology.

Thank you again for the opportunity to testify on this important topic.

[The prepared statement of Mr. Sant follows:]

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

JULY 19, 2017

CARBON UPCYCLING: TURNING CARBON DIOXIDE (CO_2) INTO CO_2NCRETE

WRITTEN TESTIMONY:

GAURAV N. SANT
ASSOCIATE PROFESSOR AND HENRY SAMUELI FELLOW: CIVIL AND ENVIRONMENTAL ENGINEERING, MATERIALS SCIENCE AND ENGINEERING, AND THE CALIFORNIA NANOSYSTEMS INSTITUTE
UNIVERSITY OF CALIFORNIA, LOS ANGELES (UCLA)

Introduction

Thank you, Chairman Smith, Ranking Member Johnson and Members of the Committee for inviting me to appear before you as you review private sector leadership in next generation energy technology to increase efficiency, environmental benefits and consumer savings, and associated research and regulatory hurdles. As requested by the committee, I am focusing my testimony on research that we have been engaged in that seeks to convert carbon dioxide (CO_2) into a novel building material, CO_2NCRETE.[1,2] The views expressed herein are my own, and do not necessarily represent those of UCLA.

I am an Associate Professor and Henry Samueli Fellow in the Henry Samueli School of Engineering and Applied Science at the University of California, Los Angeles (UCLA). I am a civil engineer, and a materials scientist with broad ranging expertise in materials synthesis, characterization and simulation.[3]

Summary

My testimony today can be summarized as follows:

Motivation: Electricity generation from coal-fired power plants alone represents 25% of CO_2 emissions from the United States (1.2 billion tons of CO_2 emitted in 2016).[4] Carbon capture and storage (CCS) has been proposed as a solution to mitigate CO_2 emissions caused by industrial activities.[5] However, CCS is not always viable due to: (i) its high cost, (ii) uncertainty in the permanence of the sequestration solution, and/or, (iii) the lack of suitable geological features in the local vicinity where CCS can be achieved.[5,6,7] Therefore, it is necessary to identify and create new pathways for the beneficial utilization of CO_2 while simultaneously yielding a permanent CCS solution.

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[2] www.co2upcycling.com
[3] https://scholar.google.com/citations?user=p_kvtiYAAAAJ&hl=en&oi=ao
[4] U.S. Energy Information Administration. *Monthly Energy Review*; DOE/EIA-0035(2017/06); Office of Energy Statistics, U.S. Department of Energy: Washington, DC 20585, June 2017; p 232.
[5] Haszeldine, R. S. *Science* **2009**, *325* (5948), 1647–1652.
[6] Kulichenko, N.; Ereira, E. *Carbon Capture and Storage in Developing Countries: A Perspective on Barriers to Deployment*; Energy and Mining Sector Board Discussion Paper, No. 25; World Bank Publications, 2012.
[7] Bachu, S. *Energy Conversion and Management* **2000**, *41* (9), 953–970.

Technical approach: A novel approach to mitigate CO_2 emissions is by *upcycling* or beneficially utilizing industrial wastes that may be in the form of solids, liquids, or vapors to create new materials, e.g., CO_2NCRETE. As an example, in the case of flue gas borne CO_2, this is accomplished by converting gas borne CO_2 (i.e., by mineralization[8,9]) into stable carbonate compounds which may offer cementitious character into building materials. Not only do such innovative technologies yield environmental benefits, but they also have the potential to reduce the environmental impact of the construction sector as follows:

- *OPC production:* The production of ordinary portland cement (OPC) – the primary binding agent used in traditional concrete – results in nearly 9% of global CO_2 emissions (N.B.: 0.9 t of CO_2 are emitted per ton of OPC produced).[10,11] Therefore, the development of new cementation agents that take-up CO_2 will help reduce the CO_2 emissions associated with OPC (and concrete) production, and
- *Material recycling:* The simultaneous reuse of CO_2 and industrial byproducts (solid wastes) resulting from coal combustion creates a new paradigm in waste-to-resource recycling of materials. This creates a circular economy[12,13] paradigm between the energy and construction sectors and thus greatly enhances the sustainability metrics of both industries.

The upcycling process is accomplished by contacting calcium hydroxide ($Ca(OH)_2$, also known as portlandite) with flue gas borne CO_2.[1,2] Such portlandite may be secured by: (a) calcining limestone and hydrating the lime that results,[14,15] or (b) by leaching calcium species from alkaline industrial wastes such as slags and coal combustion residuals to produce $Ca(OH)_2$.[16,17] Following combination with fine and coarse mineral aggregates, chemical additives, water, and suitable binding agents (if needed) – similar to traditional concrete – this mixture containing $Ca(OH)_2$ forms a slurry that can be shaped into common construction elements, such as beams, columns, and slabs.

The upcycled concrete (CO_2NCRETE) production process is designed to "bolt-on" to large point-source CO_2 emitters including: petrochemical facilities, coal- and natural gas-fired power plants, and cement plants. In each case, emitted flue gas is used to both provide waste heat to hasten chemical reactions, and to provide CO_2 to ensure mineralization without imposing any additional need for emissions control. The process cycle is being designed for scalable operations to accelerate the R&D pathway towards pilot-scale trials, technology commercialization and deployment.

Impacts and benefits: CO_2NCRETE offers a transformative route for the beneficial utilization of flue gas borne CO_2 in the cementation cycle. This creates pathways to produce construction materials with up to 50% or lower CO_2 intensity than OPC.[1,2,18] Furthermore, by creating a robust CO_2 (and solid waste) off-take partnership between the energy and construction sectors, the outcomes of this work create new *sectoral* synergies which would be difficult to realize otherwise. Significantly, this CO_2 upcycling

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approach can reduce the environmental impact of electricity generation from fossil fuels, while simultaneously advancing the materials, methods and processes utilized by the construction sector.

The Role of Federal R&D Support

Financial support secured from federal agencies including the: (i) Department of Energy, (ii) Department of Transportation, and, (iii) National Science Foundation has been instrumental in enabling our work. The support of federal agencies such as those noted above, and others, is critical for enabling basic and applied R&D, technology creation and development. Broadly, with significant (competitive) international investments in R&D around the world, federal support of basic and applied R&D, in core and emerging domains such as CO_2 utilization and reuse is more important now than ever. This is because federal R&D support is vital to enable the continued creation of knowledge and technology – within universities, and national laboratories – the reservoirs of knowledge that have ensured U.S. intellectual leadership globally.

Furthermore, federal support of R&D is especially important in the case of technologies which benefit conventional industries which are unlikely to being offshored – e.g., fossil-fuel based electricity generation, and the construction sector – which feature reduced appetite for technical and commercial risk due to uncertainty in revenue, profit pressures, substantial regulatory and compliance burdens, and/or very high costs associated with the development of greenfield facilities with long operating horizons. Therefore, it becomes necessary for the government to underwrite a larger proportion of the costs associated with R&D that has the potential to benefit such industries, and in turn, the general public, until sufficient (technology) maturity is achieved.

However, once such maturity is achieved, and industry is assured of the commercial value and potential of new technology, it is expected that industry will take-over and accelerate the residual R&D pathway including commercial trials that results in market penetration, and diffusion of new technology.

Thank you again for the opportunity to testify on this important topic.

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

JULY 19, 2017

CARBON UPCYCLING: TURNING CARBON DIOXIDE (CO_2) INTO CO_2NCRETE

SHORT NARRATIVE BIOGRAPHY:

GAURAV N. SANT
ASSOCIATE PROFESSOR AND HENRY SAMUELI FELLOW: CIVIL AND ENVIRONMENTAL ENGINEERING, MATERIALS SCIENCE AND ENGINEERING, AND THE CALIFORNIA NANOSYSTEMS INSTITUTE
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Gaurav Sant is Associate Professor and Henry Samueli Fellow in the Departments of Civil and Environmental Engineering and Materials Science and Engineering and a member of the California Nanosystems Institute at the University of California, Los Angeles (UCLA).

He earned his B.S.C.E (2006), M.S.C.E (2007) and Ph.D. (2009) in civil engineering from Purdue University in West Lafayette, IN and spent a post-doctoral year (2010) at the Ecole Polytechnique Federale de Lausanne (EPFL) in Lausanne, Switzerland.

Gaurav has authored over 100 papers in peer-reviewed journals, and conference publications. Gaurav has been a recipient of the: CAREER Award (2013), Hellman Fellowship (2013), Walter P. Moore Jr., Faculty Achievement Award (2016) and J.-C. Roumain Innovation in Concrete Award (2016) and the Gustavo Collonnetti Medal (2017).

Gaurav's research is focused on better understanding the relationships between the composition, structure and properties of inorganic structural materials including: natural and synthetic minerals, concrete, glasses, alloys, and bio-materials. He has special expertise in developing new pathways for the beneficial utilization of carbon dioxide (CO_2) in construction materials.

Gaurav is a member of the American Concrete Institute, ASTM International, RILEM: The International Union of Laboratories and Experts in Construction Materials, Systems and Structures, the American Ceramic Society, and the American Chemical Society.

Chairman SMITH. Thank you, Dr. Sant.
And Dr. Venky.

TESTIMONY OFDR. VENKY NARAYANAMURTI, BENJAMIN PEIRCE RESEARCH PROFESSOR OF TECHNOLOGY AND PUBLIC POLICY, JOHN A. PAULSON SCHOOL OF ENGINEERING AND APPLIED SCIENCES, HARVARD UNIVERSITY

Mr. NARAYANAMURTI. Thank you, Chairman Smith, Honorable Minority Leader Johnson, and Members of the House Space, Science and Technology Committee. Thank you for this opportunity to speak about the role of——

Chairman SMITH. Is your mic on? There we go.

Mr. KUMARASWAMY. Can you hear me now?

Chairman SMITH. Yes. Thank you.

Mr. NARAYANAMURTI. Thank you for the opportunity to speak about the role of public policy in energy innovation.

My perspective comes from a lifetime of working in science and technology, first at AT&T Bell Laboratories, then in national labs, Sandia National Lab, and in academia as well as my recent research at the Harvard Kennedy School and my role on several committees of the National Academies and the American Academy of Arts and Sciences.

I have three main points to make to you today. First, we must break down the false dichotomy between so-called basic and applied research. In my lexicon, there's only word, research, and research must be scientific research, physics research, technology research, engineering research.

Second, in energy alone, history has shown that sometimes engineering inventions precede detailed scientific understanding and sometimes new scientific discoveries lead to new engineering inventions. This creation of the steam engine 200 years ago by James Watt led to the industrial revolution long before the science of thermodynamics, the invention of the light bulb, Edison and transformers led to the field of electrical power engineering. On the other side, the scientific work of Einstein, which showed the connection between mass and energy, and the work of Enrico Fermi on nuclear fission led eventually to nuclear power.

My second point is that government has an important role in fostering energy innovation done in the proper way, which couples the desire to understand and the desire to create new things. That's what America is about, in my view. If you do not combine so-called basic and applied research, it's a missed opportunity. We learn by doing. Everything I do in class, we learn by doing. The private sector in energy in particular does not invest appropriately long-term R&D. In fact, that's through widely of the American economy because of the global competition and because the fruits of this research cannot be easily captured because of the risks and the breadth of those values. This leads to valleys of death which government funding is needed to overcome. The early stage I, which is where I'm expert of transformative, it really is important because in fact that—the risks are huge but the gains also can be very large, high risk, high reward, as Honorable Johnson mentioned.

Technology transfer, secondly, is a body contact support. It requires interactions, collaboration between actors from places like the national labs, universities, and the private sector.

I now want to turn to a few points on the role of the U.S. Department of Energy, which has its mission general science as well as energy and national security. In the energy space, Department of Energy investments in the past have led to major technological advances such as the shale gas revolution, which we are using the fruits of today. It was done in the 1980s when people at the DOE and the Gas Research Institute helped an entrepreneur by the name of Mitchell, Mitchell Energy. The big companies didn't want to do it, and it was not of course cost-effective then but today it has become a huge effect here, and similarly, nuclear power, which has also been mentioned, and solar photovoltaics. This has often been done by the so-called applied offices in the DOE. The full potential of the Department of Energy's work in this space can only be realized by further breaking down the boundaries between basic and applied research. Recent attempts to break down this boundary and the creation of interdisciplinary research efforts through energy Frontier Research Centers, Energy Innovation Hubs, and ARPA–E were, in my view, the steps in the right direction including the creation of a unified Under Secretary for Science and Energy. We do want to break down these barriers, and if I may be, as a respectful reminder, point to this Committee which also has responsibility for the National Science Foundation. Eric Block, who came from IBM and understood the industrial lab culture in the 1980s, changed many of the NSF features in a very positive direction. He created physics frontier centers, he created science and technology centers, and he created engineering research centers, which have a 40-year history of great success and have been evaluated in books. The recent constructs at DOE in fact emulate them. Energy Innovation Hubs are like science and technology centers and like engineering research centers, and they deserve to be funded just as the physics frontier center. So this not against the basic research; it is how you keep the boundary.

So I would like to say the great diversity and complexity in energy science and technology calls for a portfolio approach both in terms of content and management. I did not mention ARPA–E. ARPA–E is a slightly different construct, which where actually the program managers modeled like DARPA to actually go for the high-risk reward, and we have done studies on it which I can speak about later in questioning, which actually shows enormous effort which ARPA–E has also done.

So in closing, I believe we are in a critical juncture and our choices today will have far-reaching consequences. I cannot overemphasize the importance of government support of energy innovation across the basic-applied divide and enhancing cooperation and collaboration between academic, national laboratories, and industry.

Thank you.

[The prepared statement of Mr. Narayanamurti follows:]

Written Testimony of

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Before the
House Committee on Science, Space, and Technology

July 19, 2017

Dear Chairman Smith, Ranking Member Johnson, and distinguished Members of the Committee,

Thank you for offering me the opportunity to submit testimony to the Committee. It is an honor to be able to offer my perspective on a topic that is of great importance to the national interest.

My name is Venkatesh Narayanamurti. I am currently the Benjamin Peirce Research Professor of Technology and Public Policy at Harvard University. I was formerly the Dean of the Harvard John A. Paulson School of Engineering and Applied Sciences and Dean of Physical Sciences at Harvard. From 1992 to 1998 I served as Dean of the College of Engineering at the University of California at Santa Barbara.

From 1987 to 1992, I was Vice President of Research at Sandia National Laboratories. Much of my scientific research career was at the AT&T Bell Laboratories where I served first as Head of Semiconductor Electronics Research and then as Director of Solid State Electronics Research. It was in these roles that I came to understand the two key principles that underlie my testimony. Namely, that innovation is fostered when control over the research agenda resides as close as possible to the researchers in the lab; and that innovation is hindered by the traditional "linear model" that bifurcates research into categories of "basic" and "applied".

My testimony also stems from policy research I have conducted with fellow scholars at the Belfer Center for Science and International Affairs at the Harvard Kennedy School (HKS). Our group has led research on supporting decisions about the optimal levels of DOE R&D investments in various energy technologies considering technology uncertainty, the structure and management of research institutions, and the linkage between DOE and the private sector.

In addition, my recent service as Foreign Secretary (2011 to 2015) of the U.S. National Academy of Engineering, which involved many global interactions, has given me a broader view of R&D in an era of increased global competition. I currently serve on the Board of Directors of the American Academy of Arts and Sciences and co-chaired its 2013 report, "ARISE II: Unleashing America's Research & Innovation Enterprise." I was also a member of the American Academy's panel for its 2014 report, "Restoring the Foundation: The Vital Role of Research in Preserving the American Dream," co-chaired by Norm Augustine and Neal Lane.

This testimony was prepared in consultation with my colleagues with whom I have worked closely at the Harvard Kennedy School: Prof. Laura Diaz Anadon now at the University of Cambridge, Prof. Gabriel Chan now at the University of Minnesota, Dr. Amitai Bin-Nun now at Securing America's Future Energy, and Dr. Anna Goldstein. I also want to acknowledge the contributions of collaborators who have influenced my thinking over the years, including Dr. Jeff Tsao at Sandia National Laboratories and Prof. Tolu Odumosu now at University of Virginia.

Summary

The DOE is unique among federal R&D agencies in its multiple missions: "General" Science, National Security, and Energy. It is a major funder of research in physical sciences and engineering, and it oversees 17 National Laboratories. In this testimony, I will concentrate on R&D for the energy mission of DOE. Specifically, I will emphasize the need for support for transdisciplinary research and better integration of research efforts across academia, government, and industry in the energy space.

During my time as a researcher and research director at Bell Labs, Bell Labs produced major breakthroughs in semiconductor materials engineering that led to new scientific discoveries; these discoveries in turn enabled today's wireless and optical communication systems. The transformative impact of R&D at Bell Labs provides an important lesson for DOE research management: the creation of new technology requires the close integration of activities typically classified as "basic research" and "applied research." The boundary between "basic" and "applied" research is arbitrary and counterproductive. The processes of discovery and invention do not happen in isolation—the two must be holistically managed to maximize the societal benefit of research investments.

Strengthening federal energy R&D investments is especially important, given the low levels of private investment in energy R&D and the large potential for economic growth from new and improved energy technologies. DOE must continue to adopt a portfolio strategy that includes a diverse range of research management approaches, in addition to a diverse set of technologies. Reducing funding for so-called "applied" research through EERE and the other technology offices would severely undercut the ability of DOE-funded research to address energy goals and US competitiveness. DOE has taken several positive steps over the last 10 years to more tightly integrate science and engineering research activities across the "basic"/"applied" research divide, including the creation of ARPA-E. Continued efforts along these lines should be encouraged.

Opportunities exist to reform DOE's approach to energy R&D investment so that new discoveries and new inventions can more rapidly be transferred to the private sector. DOE's ability to advance its mission is hindered by the "stovepiping" of research funding streams separately administered by the Office of Science and the "applied" energy offices and limitations to National Lab director discretion. Changes in management will decrease overhead costs and improve the effectiveness of R&D funds at DOE; any funding adjustments have to be made with a scalpel, not an axe.

Suggested Readings

1. National Research Council (2007), "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future."
2. American Academy of Arts & Sciences (2013), "ARISE II: Unleashing America's Research and Innovation Enterprise."
3. Narayanamurti, V., Odumosu, T. (2016), *Cycles of Invention and Discovery: Rethinking the Endless Frontier*, Harvard University Press, Cambridge, MA, and references cited therein.
4. Anadon, L. D., Bunn, M., & Narayanamurti, V. (Eds.). (2014). *Transforming US Energy Innovation*. Cambridge University Press.
5. Anadon, L. D., Chan, G., Bin-Nun, A. Y., & Narayanamurti, V. (2016). The pressing energy innovation challenge of the US National Laboratories. *Nature Energy, 1*, 16117.

1. There is harmony between public support for "basic" and "applied" energy research

Scholars and practitioners of science and technology have largely moved past the once dominant "linear model" of innovation, in which "basic" research is thought to precede "applied" research. Contemporary research describes the process of technological innovation with a "connected R&D" model, where innovation is not separated into "basic" and "applied" activities, but rather is one continuous activity-space; activities normally classified as "applied" and "basic" are mutually reinforcing and chronologically sequenced in a variety of ways. This connected model also emphasizes the knowledge feedback that develops when technologies are put into practical application. Under this new paradigm, which is considered a better description of how engineers and scientists actually operate, new inventions in the domain of engineering enable deeper understanding in the domain of science with a comparable frequency to the reverse direction of influence.[1,2]

History abounds with examples of the interdependence of science and engineering, especially in energy. The invention by James Watt of the steam engine led to the scientific theory of thermodynamics. The invention of the light bulb by Edison and the work of Tesla and Westinghouse on transformers for long distance electricity transmission led to the emergence of the field of electrical engineering for power generation. Einstein's seminal scientific work on relativity eventually led to the discovery of nuclear fission and the development of nuclear power. America's growth as an economic superpower is in many ways connected to its frontier spirit and superior ability to exploit the virtuous cycle of scientific discovery and engineering inventions to meet societal goals. This spirit is still alive and well in some places (e.g. the information technology sector), and yet the level of investment necessary to advance both science and technology in the energy space is prohibitively large for the self-funded "tinkerer."

The unity of "basic" and "applied" research activities was a major factor in the highly productive corporate R&D activities in the 20th century. Examples abound from AT&T Bell Labs, IBM, Xerox, DuPont and General Electric. My own experience at Bell Labs, alongside the history of the invention of the transistor and the discovery of the transistor effect, illustrates the importance of breaking down barriers between science and engineering. In the 1970's and 1980's, Bell Labs made enormous strides in artificially-tailored thin-film materials, which led to new scientific discoveries in semiconductor quantum physics. These advances led *simultaneously* to the creation of devices like high-mobility transistors, which are in every cell phone, and tiny communications lasers, which allow high speed fiber optic communications across the globe.

Since my time at Bell Labs, corporate R&D has shifted dramatically toward only those R&D activities that can produce immediate returns.[3] This leaves the public sector with the responsibility to support long-term, mission-focused R&D funding. And yet, mission-focused government R&D programs must not be limited to only funding science that is remote from applications. In order to achieve long-term technological progress, the processes of discovering new knowledge and inventing new technology must be coupled. The scientists and engineers, particularly those working on energy-related topics, in U.S. universities and national labs depend on public funding to be able to create the

[1] Narayanamurti, V, Odumosu, T. (2016). *Cycles of Invention and Discovery: Rethinking the Endless Frontier*. Harvard University Press, Cambridge, MA.
[2] American Academy of Arts & Sciences (2013), "Arise II: Unleashing America's Research and Innovation Enterprise Transforming U.S. Energy Innovation."
[3] Arora A., Belenzon S., Patacconi A. (2015). "Killing the Golden Goose? The Decline of Science in Corporate R&D." NBER Working Paper Series, 20902.

new ideas that will support the nation's economic growth, security, and environmental well-being in the future.

In addition to the critical responsibility for funding research, government-sponsored programs must also support exploratory technology development. When new knowledge is derived from publicly-funded research, it must be shepherded across the "valley of death" before it finds an application suitable for transition to private sector development. The role of the government is to construct a bridge between scientists and engineers thereby creating both new ideas and new private companies focused on short-term product markets. Exactly how far this support should continue in the maturation of any given technology, from exploratory development toward manufacture and deployment, can be argued, but it is clear that government has an important role to play in supporting technologies across the "valley of death."

While the argument I have outlined above for public support throughout the innovation cycle is true for many areas of technology, it is especially urgent in the case of energy innovation. The markets for energy technologies are generally large, highly regulated, and based on long-lived hardware and infrastructure. Additionally, electricity and fuels—the main products of the energy sector—are sold as homogeneous commodities, making it hard to charge a premium for new ways of producing them. Partly as a result of these considerations, the incentive for private actors to invest in innovation is particularly low for energy technologies; the energy sector has one of the lowest rates of innovation per unit of revenue in any sector, both in the U.S.[4] and globally.[5] At the same time, the potential social benefits from energy innovation are particularly high, as explained in the following section.

2. DOE plays a critical role in U.S. energy innovation

The United States is facing both a set of challenges and opportunities related to its energy system. The challenges are global in nature and cut across issues of national security, economic growth, and environmental protection. Despite rapid increases in domestic crude oil production over the last six years, in 2016, the United States spent $7.3 trillion on oil imports from foreign countries.[6] In 2005, the most recent year a comprehensive assessment was conducted, the human health and environmental impacts of energy use in the United States (excluding any effect of climate change), was $120 billion.[7] Meanwhile, there are opportunities associated with our evolving energy system; the energy sector created 300,000 new jobs in 2016, representing 14% of all job creation in the United States.[8] This was led by 25% growth in employment in the solar sector and 32% growth in the wind sector.

The United States has entered an unprecedented era of globalization and economic competition. Achieving economic prosperity in this new era will require American companies to outcompete companies in an increasing number of countries around the world. Other countries are ramping up

[4] The Breakthrough Institute (2011). "Bridging the Clean Energy Valleys of Death."
[5] The Global Energy Assessment (2012). *Chapter 24: Policies for the Energy Technology Innovation System*
[6] U.S. Census Bureau, Economic Indicators Division. https://www.census.gov/foreign-trade/statistics/historical/petr.pdf
[7] U.S. National Research Council (2010). *Hidden Costs of Energy*.
[8] U.S. Department of Energy (2017). "U.S. Energy and Employment Report."

their public support for energy R&D.[9] If the United States withdraws support for energy R&D programs, China, Germany, Japan, and others will seize the opportunity to lead global markets in new technologies. Meanwhile, innovation is a fundamental driver of economic vitality in every Congressional district in the country.[10] Supporting innovation at the federal level will create economic opportunities nationwide and ensure that American companies have access to the most advanced inventions and discoveries.

To promote competitiveness of American companies, public sector R&D investments must be at least sustained. At a national level, there are increasing returns to innovation, meaning that the companies and countries that gain initial advantage in a technological area are much more likely to increase their advantage, while those who are behind tend to fall further behind. For example, a country with a technological advantage in new forms of energy production can use this advantage to capture market share and push out other countries, attracting further follow-on innovation by investors. Thus, early technological advantage, if sustained through strategic investments, begets further technological advantage in areas that build on the initial technology as catching up becomes harder and harder.

Energy R&D funding has higher economic returns than many other forms of investment. There is considerable evidence that DOE energy R&D investment has stimulated additional private investment, serving as a catalyst for greater overall innovation.[11,12] Several prominent studies by experts,[13,14] bipartisan groups,[15] and business leaders[16] over the past couple of decades have called for significantly greater U.S. government spending on energy R&D. These studies have concluded that there would be significant benefits to the U.S. economy of increasing energy R&D. It has been estimated that the economic returns to increasing energy R&D by DOE are very significant and would still be positive if funding were increased by a factor of 10.[17]

Inconsistent support for DOE R&D programs has led to budget fluctuations that undermine the effectiveness of R&D investments and should be avoided. Implementing effective energy R&D programs requires a minimum of a 3-5 year planning horizon so that technical expertise can be directed toward an innovation mission, physical scientific equipment can be prepared and fully

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[9] Anadon, LD (2012). "Missions-oriented RD&D institutions in energy: a comparative analysis of China, the United Kingdom, and the United States." *Research Policy* 41(10), 1742-1756.
[10] Information Technology & Innovation Foundation (2016). *High-Tech Nation: How Technological Innovation Shapes America's 435 Congressional Districts.*
[11] Howell, S. (2017). "Financing Innovation: Evidence from R&D Grants." *The American Economic Review* 107 (4), 1136-1164.
[12] Chan, G. (2015). *Essays on Energy Technology Innovation Policy.* PhD thesis Ch. 2, Harvard University, Cambridge, MA.
[13] PCAST (2010). "Report to the President on Accelerating the Pace of Change in Energy Technologies through an integrated federal energy policy." Washington D.C. President's Council of Advisors on Science and Technology. Executive Office of the President.
[14] Anadon, LD, Chan, G, Lee, A. (2014). "Expanding, and improving targeting of, U.S. investment in energy innovation: an analytical approach." In *Transforming U.S. Energy Innovation.* Eds. LD Anadon, M Bunn, V Naranayanamurti. Cambridge University Press.
[15] NCEP (2004). "Ending the energy stalemate. A bipartisan strategy to meet America's energy challenges." Washington D.C. The National Commission on Energy Policy.
[16] American Energy Innovation Council. (2017). "The Power of Innovation: Inventing the Future."
[17] Chan, G, Anadon, LD. (2016). "Improving Decision Making for Public R&D Investment in Energy: Utilizing Expert Elicitation in Parametric Models." EPRG Working Paper 1631 and Cambridge Working Paper in Economics 1682. University of Cambridge. http://www.eprg.group.cam.ac.uk/wp-content/uploads/2017/01/1631-Text.pdf

exploited, and the right people recruited, trained, and supported. The highly volatile DOE R&D appropriations for specific programs have made this kind of long-term planning more difficult.[18] A more stable environment would increase the capability for program managers and scientists to pursue higher-risk, higher-reward research. Reducing volatility in funding could be achieved by following a multi-year high-level strategy, along the lines of those suggested by the first and second Quadrennial Technology Reviews.[19] Programs should be evaluated on a regular basis, and those that under-perform with regard to holistic measures of knowledge and technology advancement, as opposed to narrower metrics, should be cut.

3. EERE and ARPA-E are necessary to achieve strategic energy policy objectives

DOE energy R&D investments have advanced the scientific and technological frontier and are critical components of the U.S. national innovation system. These investments have made our economy more dynamic,have created new technological opportunities for American companies to deliver services here and to compete internationally, and have driven employment in every region of the country. In particular, I would like to highlight the impact of two R&D funding sources within DOE: EERE and ARPA-E.

EERE

The Office of Energy Efficiency and Renewable Energy (EERE) has existed under various names since the inception of the Department of Energy in 1978. Its strategic goals are to accelerate the development and increase the usage of sustainable transportation, renewable energy, and energy efficiency technologies. It also seeks to promote the domestic manufacture of clean energy technology and increase grid resiliency, reliability, and efficiency. EERE is organized on the principle of investing in high-impact activities that could not be realized without its participation. To this end, EERE works with academia, industry, and national labs on R&D, technology validation, and reducing market barriers for new technologies. Importantly, it also oversees the National Renewable Energy Laboratory in Golden, Colorado (NREL), which hosts state-of-the-art testing facilities and conducts research in renewable energy technologies.[20]

According to DOE, recent third-party evaluations found that "an EERE taxpayer investment of $12 billion has already yielded an estimated net economic benefit to the United States of more than $230 billion, with an overall annual return on investment of more than 20%."[21] A 2001 report of the independent National Research Council (NRC) found that DOE investments in energy efficiency research had yielded considerable net economic benefits, even apart from environmental benefits from reduced pollution and national security benefits from reduced petroleum consumption. The NRC

[18] Anadon, LD, Chan, G, Lee, A. (2014). *Ibid.*
[19] U.S. Department of Energy. "The Quadrennial Technology Review." https://energy.gov/under-secretary-science-and-energy/quadrennial-technology-review
[20] U.S. Department of Energy. "About us." https://energy.gov/eere/about-office-energy-efficiency-and-renewable-energy
[21] U.S. Department of Energy. "About the Office of Energy Efficiency and Renewable Energy" https://energy.gov/eere/about-office-energy-efficiency-and-renewable-energy

found that from 1978 to 2000, EERE invested $7 billion (1999 dollars), which yielded a total economic benefit of $30 billion by 2000.[22]

One example of EERE's important role in the American energy innovation system is its SunShot Initiative. Since 2011, SunShot has funded R&D and demonstration projects with public and private partners; EERE's budget for solar technologies was $233 million in 2015. Meanwhile, the U.S. solar power industry has grown enormously due to continuous cost reductions for residential, commercial, and utility-scale photovoltaic systems. The total power generated by solar photovoltaics in the U.S. increased by a factor of 2,000 during the decade from 2007-2016.[23] According to a 2017 DOE report, there were 374,000 solar industry jobs in the United States in 2016, slightly higher than the number of jobs in the natural gas sector (362,000 jobs) and more than twice that of coal sector jobs (160,000 jobs).[24] In terms of growth rates, the number of jobs created in 2016 by the U.S. solar power industry was nearly 5 times greater than the number of jobs created by the oil, natural gas, and coal sectors combined.

As another example of EERE's impact, their Solid-State Lighting (SSL) program was instrumental in developing and promoting the adoption of solid-state lighting. The National Research Council performed an assessment of these investments and concluded, "DOE has done an impressive job in leveraging a relatively small level of funding to play a leading role nationally and internationally in stimulating the development of SSL."[25] The progress in SSL development and deployment resulted from a combination of R&D and DOE efficiency standards established in the bipartisan Energy Independence and Security Act of 2007. According to the Department, the introduction of SSL could save Americans $50 billion annually in lighting costs by 2035.[26]

ARPA-E

Modelled after DARPA to fund transformative research, the Advanced Research Projects Agency for Energy (ARPA-E) was established by the America COMPETES Act of 2007 and funded by the Recovery Act (ARRA) of 2009. Its goal was to support technology ideas that were not being funded by the private sector or other DOE programs. ARPA-E has received broad bipartisan support. In the FY 2017 budget proceedings, 44 Democrats and 26 Republicans supported an amendment by Sen. Schatz to increase funding for ARPA-E; the House passed a similar amendment by Rep. Schiff by a voice vote[27]. ARPA-E's funding has been relatively stable over the past 3 years (2014-2016) at $280-290 million/year, which constitutes about 7-8% of all DOE funding for energy research development and demonstration (RD&D).[28]

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[22] National Research Council (2001). *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000.*
[23] Energy Information Administration (December 2016). "Electric Power Monthly: Table 1.1.A. Net Generation from Renewable Sources: Total (All Sectors), 2006-December 2016."
[24] Department of Energy (2017). *U.S. Energy and Employment Report.*
[25] National Research Council (2013). *Assessment of Advanced Solid State Lighting.*
[26] U.S. Department of Energy (2017). "DOE Solid-State Lighting Program: Modest Investments, Extraordinary Impacts." https://energy.gov/sites/prod/files/2017/01/f34/ssl-overview_jan2017.pdf
[27] S.Amdt. 3802 to S.Amdt. 3801 to H.R. 2028 (Energy and Water Development and Related Agencies Appropriations Act, 2016)
[28] Gallagher, KS and Anadon, LD. (2016). "DOE Budget Authority for Energy Research, Development, & Demonstration Database." Harvard Kennedy School, Belfer Center. Available at: https://www.belfercenter.org/publication/doe-budget-authority-energy-research-development-demonstration-database

One characteristic that differentiates ARPA-E from other DOE programs is the recruitment and empowerment of program managers on short-term contracts.[29] Another is its direct reporting to the Secretary of Energy, rather than being embedded in the existing structure of DOE. These features allow the agency to pursue priorities of long-term importance, in consultation with academics and industry professionals, without being subject to political interference on spending priorities.

The goal of ARPA-E is to fund projects that may lead to long-term transformation in our energy system, to increase efficiency, national security, and environmental protection. This year, a study from the National Academies found "clear indicators that ARPA-E is making progress toward achieving its statutory mission and goals."[30] ARPA-E has funded over 400 projects across 39 states, including 42% from universities, 32% from small businesses, 14% from large businesses, 8% from Federally Funded Research and Development Centers, and 4% from non-profits. As of this year, the $1.5 billion in public funds that have been awarded through ARPA-E has attracted $1.8 billion in follow-on private investment.[31]

Because it is impossible to predict the long-term impact of R&D in advance, and given the long timescales involved in demonstrating and deploying energy technology,[32] the full impact of ARPA-E investments will only be fully realized in a decade or two. However, the international push to find cost-effective ways to accelerate energy innovation has provided impetus for researchers to start documenting what we know about the short-term success of ARPA-E projects.

Non-partisan evaluation and research, including the National Academies study, has begun to shed light on the results of ARPA-E's first several years. It appears that ARPA-E has funded a distinct portfolio of technology areas when compared to other DOE programs and the bulk of U.S. cleantech startups. In particular, ARPA-E has invested a larger fraction of its startup-led projects in energy storage.[33] Interestingly, previous work has identified energy storage as a particularly high social-return opportunity for public energy R&D.[34] Other results show that ARPA-E-funded projects are more likely to produce a patent when compared to projects funded at a similar level elsewhere in DOE.[35] This advantage may relate to the fact that ARPA-E program directors are empowered to select risky projects for funding, and yet these projects perform as well as those with higher ratings from external reviewers on metrics of publications, patents, and market engagement.[36]

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[29] Bonvillian, W.B., Van Atta, R. (2011). "ARPA-E and DARPA: applying the DARPA model to energy innovation." *Journal of Technology Transfer* 36, 469–513.

[30] National Academies of Sciences, Engineering and Medicine (2017). *An Assessment of ARPA-E*. The National Academies Press, Washington, D.C.

[31] Advanced Research Projects Agency – Energy (2017). "ARPA-E Projects Receive more than $1.8 Billion in Private Follow-on Funding for Transformational Energy Technologies."

[32] Grubler, A, Wilson, C, Nemet, GF. (2016). "Apples, oranges, and consistent comparisons of the temporal dynamics of energy transitions." *Energy Research & Social Science* 22: 18-25.

[33] Goldstein, AP, Doblinger, C, Anadon, LD. (2017). Unpublished research. Please contact Anna P. Goldstein anna_goldstein@hks.harvard.edu for more information.

[34] Chan, G, Anadon, LD. (2016). *Ibid.*

[35] Goldstein, AP, Narayanamurti, V. (2017). "Simultaneous Pursuit of Discovery and Invention in the U.S. Department of Energy." Ongoing research.

[36] Goldstein, AP, Kearney, MJ. (2017). "Uncertainty and Individual Discretion in Allocating Research Funds." Ongoing research.

These early indicators suggest that the institutional model of ARPA-E complements efforts elsewhere in the innovation system and should be preserved. Public investment in risky, uncertain, paradigm-transforming research is necessary in order to create new technologies which can grow into entirely new industries. The benefits to this type of research cannot be captured by any single company, so private investment is severely limited.

4. Opportunities for improved performance

To be most effective, DOE investments in energy R&D should be targeted at all stages of the innovation process. Unfortunately, the current DOE structure consists of siloes between artificially determined budget categories based on outdated and counterproductive characterizations of "basic" and "applied" research. In reality, the distinction between so-called "basic" and "applied" research is impossible to determine, and the most transformative R&D occurs with seamless interactions across disciplines of science and engineering. Therefore, making R&D budget decisions along this artificial line necessarily limits creativity and out-of-the-box thinking required for the creation of new technologies.

Several programs created within DOE in recent years, including ARPA-E, have fostered transdisciplinary research and supported activities across the "basic-applied" divide. These new programs serve an important function, while also functioning in combination to create a portfolio of different approaches. The Energy Innovation Hubs are a set of 5-year awards made to a partnership between universities, national labs, and private companies formed around a specific technological mission. First funded in 2009, the Hubs were modeled after the Manhattan Project and the AT&T Bell Laboratories.[37] Each of the current Hubs is based at a National Lab; extending this model outside of the labs may bring additional benefits. Also created in 2009, the Energy Frontier Research Centers (EFRC) are smaller competitive awards, organized around "grand challenges" in energy-related research. In addition to a portfolio of management approaches, DOE must also support a diverse portfolio of programs spanning multiple primary energy resources, multiple technology readiness levels, and multiple timescales for application of those technologies.

To enhance the public benefits of DOE's energy R&D, a closer integration is needed between activities typically managed by the Office of Science and the technology offices. The appointment in 2014 of a single Undersecretary for Science and Energy is a step in the right direction for DOE R&D management; this organizational structure should be maintained. This move enabled the creation of crosscutting initiatives, wherein multi-office teams coordinate funding for a set of specific technical challenges, such as grid modernization. Further steps to improve the structure at the Assistant Secretary level may be needed. One possible improvement is to create a new "Office of Energy Research" that would combine activities across the full spectrum of energy-related research. This office could coordinate initiatives that fill existing departmental functions, including core research programs in science and engineering that span the range from distant commercial relevance (e.g. condensed matter and atomic physics) to a strong technology focus (e.g. energy storage). An example of such initiatives can be found at the National Science Foundation, which has since the 1980's successfully fostered interdisciplinary research through Physics Frontier Centers, Science and

[37] Anadon, LD. (2012). *Ibid.*

Technology Centers, and Engineering Research Centers; these efforts have been evaluated very positively in their impact over multiple decades.[38]

The DOE's 17 National Laboratories are major investments in long-term R&D in the physical sciences and engineering. The lab system contributes significantly towards energy innovation, but could extract better outcomes with improved management structures.[39] As discussed in our recent work,[40] this would require increasing the funding for lab-directed research and development (LDRD) at the margin to give more control over funds to those closer to the research. We also recommend changes in the contracting procedures to provide incentives for collaboration between the labs and the private sector, including more support for technology transfer through the Lab-Embedded Entrepreneurship Program (e.g. Cyclotron Road), Sandia's efforts to promote entrepreneurship, and other initiatives. These issues require attention in parallel with other needed changes, in order to enhance the benefits of publicly-funded DOE research for the U.S. energy innovation system.

5. Concluding remarks

Congressional support for energy R&D investments from the DOE has a long bipartisan history that should continue. These public investments in energy R&D have been critical in addressing the energy security challenges faced by the country since the oil crisis of the 1970s. More recently, DOE R&D investments in all forms of energy have paved the way for some of the most vibrant economic sectors in terms of employment (in both fossil and renewable sectors). Sustaining strong public support for DOE's energy R&D mission is more important now than ever, as our security, economic, and environmental challenges are becoming more pressing for Americans everywhere and as other nations are working to position themselves as global leaders. After nearly 40 years of experience, independent studies of DOE R&D investments have shown that, in total, DOE R&D investments have strongly advanced American interests. Reducing these investments now would be a critical strategic failure. Instead, DOE R&D investment should be strengthened and managed more strategically through tighter integration of "basic" and "applied" research, with concurrent organizational changes and greater engagement with the private sector.

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[39] Glauthier, T. J. et al. (2015). "Securing America's Future: Realizing the Potential of the DOE National Laboratories. Final Report of the Commission to Review the Effectiveness of the National Energy Laboratories Vol. 1."
[40] Anadón LD, Chan G, Bin-nun AY, Narayanamurti V. (2016). "The Pressing Energy Innovation Challenge of the US National Laboratories." *Nature Energy*, 16117.

Short biography

Venkatesh Narayanamurti is the Benjamin Peirce Research Professor of Technology and Public Policy in the Harvard John A. Paulson School of Engineering and Applied Sciences and the Kennedy School of Government. From 2009 to 2015 he was Benjamin Peirce Professor of Technology and Public Policy and Professor of Physics at Harvard and concurrently served as Director of the Science,Technology and Public Policy Program at the Belfer Center of Science and International Affairs. He was formerly the John L. Armstrong Professor and Founding Dean of the School of Engineering and Applied Sciences and Dean of Physical Sciences at Harvard. Previously he served as the Richard A. Auhll Professor and Dean of Engineering at the University of California at Santa Barbara. Prior to that he was Vice President of Research at Sandia National Laboratories and Director of Solid State Electronics Research at Bell Labs. He obtained his PhD in Physics from Cornell University and has an Honorary Doctorate from Tohoku University. He is an elected member of the American Academy of Arts and Sciences, the National Academy of Engineering and the Royal Swedish Academy of Engineering Sciences, and a Fellow of the American Physical Society, the American Association for the Advancement of Science, the IEEE, and the Indian Academy of Sciences. He has served on numerous advisory boards of the federal government, research universities, National Laboratories and industry. From 2011 to 2015 he served as the Foreign Secretary of the U.S. National Academy of Engineering. He currently serves on the Board of Directors and the Academic Council of the American Academy of Arts and Sciences. He is the author of more than 240 scientific papers in different areas of condensed matter and applied physics and the author of two books. He has written extensively and lectures widely on solid state, Energy technologies, computer, and communication technologies, and on the management of science, technology and public policy.

Chairman SMITH. Thank you, Dr. Venky. You certainly know how to message research.

We'll now go to Mr. Kumaraswamy. We look forward to your comments.

TESTIMONY OF MR. KIRAN KUMARASWAMY, MARKET DEVELOPMENT DIRECTOR, AES ENERGY STORAGE

Mr. KUMARASWAMY. Thank you, Chairman Smith and distinguished Members of the Committee. I'm honored to testify in front of you today on the topic of energy innovation and private sector leadership and commercializing new technologies.

Innovation can and will transform the energy sector and in turn, people's lives. Bringing change to the industry is part of our DNA at AES and, in many ways, is what we do best. AES was started 35 years ago by two former government employees, Roger Sant and Dennis Bakke, who saw an opportunity in the emerging independent generation market and we continue to grow by innovating new solutions to serve emerging power sector needs.

I think innovation is very different from invention. Invention is a new idea. Innovation is actually doing something with the idea or applying an existing idea in a new way to drive a greater impact. That means that to AES, innovation can happen not just through technology, but by thinking about business models differently or modifying market structures. It's an approach we call applied innovation.

There is no better example of our applied innovation approach than in our energy storage business. We've come far from where we started ten years ago in the energy storage business. Back then, battery based energy storage on the grid was experimental, and did not exist as a business opportunity. Today, it is a proven solution and is operating successfully across the country and in several global markets. We stand at the beginning of the next big scaling up, taking this vital technology to more customers, more countries, and more grids around the world.

In the context of today's discussion and applied innovation, it's pretty important to understand how we got here. In 2007, AES Energy Storage was founded as a subsidiary of AES to carry forward our initial survey of advances in battery technology and power electronics. At the time, no one had designed a large-scale energy storage system using lithium-ion batteries. The conventional wisdom of the time was that batteries could not meet the challenges of utility-scale performance. As lithium-ion technology emerged, our team believed we had found useful business cases for battery-based energy storage systems

We moved forward with designing and building the first megawatt-scale lithium-ion battery energy storage project. Several years later, with 20 projects now and 398 megawatts deployed and awarded across seven different countries globally, we've helped ensure more customers in more locations can benefit from energy storage.

In 2014, in California, we demonstrated that batteries could compete successfully against peaking power plants, securing the world's first power purchase agreements for energy storage to serve a utility customer for 20 years, and still the largest contracted energy storage project in the world.

Just last week, Siemens and AES announced we will join forces to create Fluence, a new global energy storage technology and services company that unites the scale, experience, and reach of its two parent companies.

With the market at an inflection point, what did we, as a private company, learn about commercializing next-generation technologies in the power market? I'd like to make four points to the Committee.

First, the existing power market is not designed to reward innovators, and many of the needs reside within the network without any capability for compensation. Many of the rules in the current power markets were put in place for traditional generation and do no fully account for technical and performance characteristics of advanced technologies like energy storage. It is important to remedy these regulatory concerns as soon as possible. The federal government has an important role to play here to ensure markets are fully competitive and have the policy in place to catch up with the technology. Otherwise, market rules set up several years ago become an unintended roadblock for commercializing energy storage.

The Federal Energy Regulatory Commission currently has a Notice of Proposed Rulemaking related to removing barriers for storage participation in wholesale power markets. These types of efforts that include reforming market regulations to enable storage to compete in markets should be accelerated.

Second, on the topic of battery chemistry research, we believe that lithium ion is mature right now and private capital from large battery manufacturing companies is moving it forward at incredible speed and investment. The government should continue funding R&D on other early-stage battery chemistries that have the potential to achieve greater capabilities in the near future.

Third, the national labs through the Department of Energy are doing a great job in advancing the modeling and visualization of benefits that energy storage brings to the grid. These are complex analytic simulations that require the use of state-of-the-art power market models and a high degree of computational rigor. The government should encourage and increase investments in the DOE and national labs to continue this important work.

Finally, the last point that I would like to make is that the federal government should continue to provide technical assistance to storage project deployments, particularly for states and utilities that are considering their first projects but may be constrained by lack of technical experience. Through our experience in the energy storage business, we have found that deploying projects in the field is the best way to enhance learning among all stakeholders.

Mr. Chairman, thank you again for the opportunity to testify today. I would like to invite you and the other Members of the Committee to visit any of our storage facilities in the United States. I am happy to take questions. Thank you.

[The prepared statement of Mr. Kumaraswamy follows:]

July 19, 2017

Written Testimony of Kiran Kumaraswamy, Market Development Director of AES Energy Storage Before the U.S. House of Representatives, Committee on Science, Space and Technology – Energy Innovation: Letting Technology Lead

Thank you, Chairman Smith, Ranking Member Johnson, Vice Chairman Lucas, Vice Ranking Member Beyer and Distinguished Members of the Committee. I am honored to testify in front of you today on the topic of energy innovation and private sector leadership in commercializing new technologies. My name is Kiran Kumaraswamy – I am a Market Development Director of AES Energy Storage, a subsidiary of The AES Corporation, a Fortune 200 global energy company headquartered in Arlington, Virginia. AES provides affordable and sustainable energy in 17 countries around the world.

Innovation can and will transform the energy sector and in turn, people's lives. Improving lives is our mission at AES and our 19,000 people around the world are energized by that mission every day. In a sector that is changing faster than ever in its history, innovation will be critical to solving society's most pressing challenges, improving the way people work and live, and providing access to cleaner electricity.

Bringing change to the industry is part of our DNA at AES and, in many ways, is what we do best. AES was founded more than 35 years ago and we continue to grow by innovating new solutions to serve emerging power sector needs. We have helped create new emissions control technologies and biomass conversions, have built new efficient power generating stations, and we have brought thousands of megawatts of wind and solar to market.

We think innovation is different from invention. Invention is a new idea. Innovation is actually doing something with the idea or applying an existing idea in a new way to drive a greater impact. That means that to AES, innovation can happen not just through technology, but by thinking about business models differently or modifying market structures.

AES has been successful by applying proven technologies, tailoring them for the power sector, and innovating commercial models to bring dependable, cost-effective power to our customers. It's an approach we call applied innovation. Applied innovation is about addressing a market issue with a proven technology, typically borrowed from outside of our industry. These solutions, when applied to our industry, can completely shift the dynamics within a market.

The smart application of technologies validated in other sectors removes the risk and speeds the cycle time to new and better, affordable solutions. AES leverages the capabilities of an established and proven supply chains from other industries to solve critical power system problems. Devising new applications of established technology gives AES and our customers the confidence that the technology is reliable.

Energy Storage: An Example of Applied Innovation at AES

There is no better example of our applied innovation approach than in our energy storage business. We are in the midst of a transition towards an increasingly renewable and decentralized energy system. Storage is playing a key role where it's already deployed in providing flexibility and resiliency, maximizing what our current infrastructure can deliver, and allowing us to more easily incorporate distributed generation onto the electric grid.

We've come far from where we started. Ten years ago, battery based energy storage on the grid was experimental, and did not exist as a business opportunity. Today, it is a proven solution and is operating successfully across the country and in several overseas markets. We stand at the beginning of the next big scaling up – taking this vital technology to more customers, more countries, and more grids around the world.

In the context of today's discussion and applied innovation, it's important to understand how we got here.

In 2007, AES Energy Storage was founded as a subsidiary of AES to carry forward our initial survey of advances in battery technology and power electronics. We saw the opportunity to use these technologies to improve the flexibility and efficiency of electric grids while running power plants more efficiently. We were bullish on the potential for lithium-ion as a technology for use in the power sector, as the technology itself had been validated in other major industries, such as consumer electronics and transportation. It also had the benefit of a well-established global supply chain, which gave us confidence that we would be able to scale up supply as demand for storage solutions grew.

At the time, no one had designed a large-scale energy storage system using lithium-ion batteries. Prior experiments in deploying batteries on the power grid proved the high value of the speed and responsiveness of batteries to improve grid reliability. However, the battery technology of the time proved unable to meet the challenge, due to its limited life and high costs. The conventional wisdom of the time was that batteries could not meet the challenges of utility-scale performance. As lithium-ion technology emerged, our team believed we had found useful business cases for battery-based energy storage systems. We moved forward with designing and building the first megawatt scale lithium-ion battery energy storage project.

By 2008, our battery-based energy storage system was ready to be tested on the grid. The team connected the first grid-scale battery by integrating two large tractor trailers of batteries to the grid in Indiana. This proved that large-scale battery-based energy storage could safely connect to an electric grid, operate as a complete system, and respond remotely to instructions sent by the grid operator, a key reliability service for all power grids.

Over the next few years, we worked closely with customers and stakeholders to prove grid-scale energy storage's feasibility, making history step-by-step: delivering the first commercial lithium-ion battery storage systems in the world in Northern Chile, and expanding our deployments in the United States in Pennsylvania, Texas, California, New York, West Virginia, and Ohio. And with every project – we were driving down costs for customers, learning, and innovating.

In 2014 in California, we demonstrated that batteries could compete successfully against peaking power plants, securing the world's first Power Purchase Agreements (PPA) for energy storage to serve a utility's customers for twenty years, and still the largest contracted energy storage project in the world. To meet the needs for these larger, long-term projects, we turned our eye towards innovating and enhancing the energy storage technologies available at the time, incorporating lessons learned and applications developed into a single battery-based energy storage platform – Advancion®.

Rendering of 100 MW/400 MWh (Energy Storage) Alamitos Energy Center Under Contract and Expected to be Completed in 2021 in Long Beach, California

We then offered the Advancion® platform to other utilities and developers, and in less than six months from contract signing, delivered the world's largest system of its kind in San Diego, California.

Today, Advancion® is one of the world's leading energy storage platforms. With 20 projects and 398 MW deployed and awarded across seven countries, we've helped ensure more customers in more locations benefit from energy storage. AES has deployed the most comprehensive and proven fleet of battery-based energy storage systems in the world, which have delivered more than 3.5 million megawatt-hours of service to-date.

The AES Corporation
4300 Wilson Boulevard
Arlington, VA 22203
aes.com

20 MW Harding Street Advancion® Energy Storage Array in Indianapolis, Indiana

Energy storage is critical for the grid's transformation to a new energy network – one that can meet the needs of our rapidly changing energy landscape and accelerate a cleaner energy future. Global demand for grid-connected energy storage is rapidly expanding. To answer that demand and transform the grid, we need to continue to drive down costs by scaling energy storage up, further and faster.

Just last week Siemens and AES announced we will join forces to create Fluence, a new global energy storage technology and services company that unites the scale, experience, and reach of its two parent companies. Subject to customary regulatory approvals, the 50/50 joint venture between Siemens and AES will deliver both the AES Advancion® and Siemens Siestorage energy storage platforms and continue to develop new storage solutions and services reaching customers in more than 160 countries.

Fluence will fill a major gap in the market by bringing together two of the industry's leading power and storage companies to create a new company that will have the power, breadth, people and footprint to continue transforming the energy landscape.

The AES Corporation
4300 Wilson Boulevard
Arlington, VA 22203
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Combined, the companies deployed or have been awarded 48 projects in 13 countries with a total capacity of 463 MW.

The energy storage market is at a point similar to what we saw with the solar industry in 2007 or 2008. Solar was at the cusp of a tremendous period of growth and the energy storage industry will follow a similar trajectory, with significant expected growth over the next 10 years. Several forecasts anticipate the global market size of grid-connected storage at more than 28 GW by 2022, and could possibly go higher if places like India achieve their renewable energy targets.

With the market at an inflection point, what did we, as a private company, learn about commercializing next generation technologies in the power sector?

First, the existing power market is not designed to reward innovators and many of the needs reside within the network without any capability for remuneration. Many of the rules in the current power markets were put in place for traditional generation and do no fully account for technical, performance characteristics of advanced technologies like energy storage. The entire infrastructure of the existing centralized power and ancillary service markets were designed for the operating characteristics of traditional generation only. One notable example of the inability of the current market to accommodate a more efficient and valuable lithium-ion battery is the IPL Advancion® Energy Storage Array. Due to various issues, including an inability by the regional grid operator (Midwest Independent System Operator, MISO) to fully utilize the storage system and limitations in dispatch modeling, the device is continuously providing valuable service to the grid, but is not compensated for doing so.

It is important to remedy these regulatory concerns as soon as possible, so that storage can provide key grid services to regional markets. The Federal Government has an important role to play here, to ensure markets are fully competitive and have the policy in place to catch up with the technology – otherwise, market rules set up several years ago become an unintended roadblock for commercializing energy storage. The Federal Energy Regulatory Commission (FERC) currently has a Notice of Proposed Rulemaking (NOPR) related to removing barriers for storage participation in wholesale power markets. These types of efforts that include reforming market regulations to enable storage to compete in markets should be accelerated.

By making the challenges and needs of the power system consistently more visible, technologies and the capital to fund them can be mobilized to address these needs. For example, the earliest instances of energy storage were based around resolving frequency management in large power systems such as the Mid-Atlantic PJM Regional Transmission Organization Power Market. This was made possible due to the fact that this market had made the need for frequency management a known need through a defined market service. In other parts of our electric sector, where we do not have organized markets, this need remains obscured. Whereas energy storage has emerged to lower the cost, improve reliability, and reduce emissions associated with frequency regulation in the organized markets, these technologies have not yet been applied in more closed power systems.

Second, on the topic of battery chemistry research we believe that lithium ion is mature and private capital from large battery manufacturing companies are moving it forward at incredible speed and investment. . The Government should continue funding R&D on other early stage battery chemistries that have the potential to achieve greater capabilities.

Third, the national labs through the Department of Energy (DOE) are doing a great job in advancing the modeling and visualization of benefits that energy storage brings to the grid. These are complex analytic simulations that require the use of state of the art power market models and a high degree of computational rigor; the Government should encourage and increase investments in the DOE and national labs, to continue this work and to share analytical methods with utilities, wholesale market operators, and other stakeholders responsible for planning, operating and maintaining the electric system. This is a critical piece of commercialization because it provides the analytic support for comparing the costs and benefits of deploying energy storage for specific applications.

Finally, the Government should continue to provide technical assistance to storage project deployments, particularly for states and utilities that are considering their first projects but may be constrained by lack of technical experience. Through our experience, we have found that deploying projects in the field is the best way to enhance learning among all stakeholders – utilities, grid operators and state regulators alike.

Mr. Chairman, thank you again for the opportunity to testify today – I would like to invite you and the other Members of the Committee to visit any of our storage facilities in the United States. I am happy to take any questions.

Thank you.

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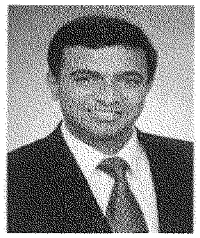

Kiran Kumaraswamy,
Market Development Director
AES Energy Storage

Mr. Kiran Kumaraswamy is a Market Development Director at AES Energy Storage. In this role, he is directly responsible for identifying markets and applications that are attractive for energy storage development and educating potential customers on the benefits of energy storage. His work involves implementing regulatory and policy solutions that create access to key markets. Kiran also works with all the electricity industry stakeholders, trade associations and regulators. Prior to joining AES, he worked as a Senior Manager in ICF International advising private sector clients on wholesale power market and transmission issues. He holds an MS in Electrical Engineering from University of Wisconsin, Madison and a BS in Electrical Engineering from the University of Madras, India.

Chairman SMITH. Thank you, Mr. Kumaraswamy.

Let me address my first question to Dr. DeWitte and Mr. Kumaraswamy, and it is this: What regulatory hurdles did you face and what do you suggest Congress do to address those regulatory hurdles? And Dr. DeWitte, we'll start with you.

Dr. DEWITTE. Thank you for the question. We're actively in that process right now, and we have a long road ahead of us, frankly. The nuclear regulatory process is—it's an ongoing and sort of everlasting process once you are commercializing a technology and putting it to field and into market. There's been a lot of concerns historically about the readiness for the Nuclear Regulatory Commission to handle advanced reactors. We found that that's generally been overstated and that they've been well prepared. In particular, recent activities around working with DOE to prepare for what are called advanced reactor design criteria as well as other efforts the NRC has undertaken to prepare themselves technically to review advanced reactor applications are paying dividends as we speak.

Our formal interactions with the regulator have gone quite well so far. However, there's still room to improve, and I think a couple of those areas focus on rightsizing regulations for reactor size and potential risk and also rightsizing security and staffing requirements. That still needs to be done. So there's still opportunities for improvement but generally we've been pleased.

Chairman SMITH. Okay. Good. Thank you, Dr. DeWitte.

Mr. Kumaraswamy?

Mr. KUMARASWAMY. Thank you, Chairman. Like I mentioned in my opening remarks, I think one of the key things in the power sector is that you have market rules that are put in place for technologies that were prevalent at that time in the marketplace, and these are commonly tailored towards traditional generation facilities, and one of the concerns that we have is that when you have advanced technologies like energy storage that are trying to get into these regional power markets, those rules don't apply directly to them so they have to be changed in order for you to allow for the capabilities and performance characteristics of these devices.

So just to give you an example, Indianapolis Power and Light, which is an AES Company, which is in the State of Indiana, we have had difficulty integrating a new 20-megawatt battery energy storage project in that regional market mainly because of the fact that the power market rules in the Midwest, independent system operator are not set up to handle the characteristics of energy storage, and so Federal Energy Regulatory Commission is doing a great job. They have that Notice of Proposed Rulemaking to remedy a lot of these issues, and I think encouraging those efforts to completion as quickly as possible once FERC actually gets the quorum would be a pretty important step for us to make sure that the technology can be brought into the market and the market can realize all of those benefits that the technology provides.

Chairman SMITH. Okay. Good. Thanks.

Dr. Sant and Dr. DeWitte and Mr. Kumaraswamy, do your technologies reduce carbon emissions? And if so, can you quantify it? But first of all, do they reduce carbon emissions, and is that significant? Dr. DeWitte—Dr. Sant, let's start with you.

Mr. SANT. Thank you, Chairman Smith. Yes, they do. I should point out the way our work is really set up, what we're trying to do is reduce the carbon dioxide emissions that are associated with cement production. So we're trying to create replacements for Portland cement, which like I pointed out, provides about, give or take, nine percent of global CO_2 emissions. Being able to reduce the CO_2 footprint associated with cement production by avoidance and by taking up CO_2 by utilization, both yield reductions in carbon dioxide. However, we should be careful to point out that this is a small number, so we're talking about a few percentage points. It's a big number if you look at it in terms of the potential reduction that you can achieve, but in the grand scheme of things, it's still only a few percent.

Chairman SMITH. Okay. Thank you, Dr. Sant.

And Mr. Kumaraswamy?

Mr. NARAYANAMURTI. Sure. Energy storage definitely has the capability to reduce the amount of emissions that we have. It's also notable that the U.S. electric grid currently has less than one percent of energy storage in the system. That's equal to about 20 minutes of the total demand that we have for energy in the country. This is in comparison to about 4 days' worth of storage that we typically find in other networks like gas networks and significantly more storage than we have in things like data networks. So just a point that the amount of energy storage that we have in the system is significantly lower in the energy system.

By increasing the amount of energy storage that we have in the grid, we can make sure that we integrate all of the renewable energy sources that we have on the system, and most importantly, help operate the existing conventional generation resources much more efficiently. Instead of cycling them back and forth, you actually get the capability to operate these existing generation facilities at more stable output blocks, which means that they actually produce less emissions, and you reduce the amount of renewable curtailment also and so there's significant environmental benefits with energy storage.

Chairman SMITH. Thanks, and Dr. DeWitte, briefly, nuclear is obviously going to have a huge impact on carbon emissions. Can you explain why and how?

Dr. DEWITTE. Yes. It has a huge impact on reducing CO_2 and other emissions because it doesn't produce any during generation and it has a massive scalable potential. One single fission event produces 50 million times as much energy as when you combust a single molecule of natural gas, so you can avoid a lot of emissions. Look at France and Sweden. They have some of the best track records for decarbonization solely due to nuclear, frankly.

Chairman SMITH. Okay. Thank you. I appreciate your answers today.

And Ms. Johnson is recognized for her questions.

Ms. JOHNSON. Thank you very much, Mr. Chairman.

Dr. Venky, we have heard from scientists and policymakers alike that there's often a false boundary drawn between basic and applied science. To some, supporting basic research is an important role that government—of government while applied research should be left to the private sector. Yet this idea that there is a line that neatly divides the two separate levels of research is not realistic and certainly goes against general understanding of scientific discovery and innovation.

As you mentioned in your testimony, you have written extensively about this issue. Would you agree with this characterization or do you really feel there is a distinctive line?

Mr. NARAYANAMURTI. So thank you very much, Honorable Minority Leader. I want to really emphasize that historically, this divide started during World War II, but really, many scholars, not just me, including economists, social scientists have done studies and have shown that this is a false dichotomy and in fact you have to actually fund all aspects of research to be effective.

My own work, which really was modeled after Bell Labs—in fact, I looked at the original speeches of Bell Labs. They were such iconic institutions which did such great science and such great technology. They made an explicit point of not breaking research up into parts. In fact, the leader of Bell Labs had arguments with Vannevar Bush on that subject because he said we do not separate them because in fact discoveries and inventions feed on each other and there's both back and forth.

So my argument is, research does need some insulation but not from engineering and technology. It is about the long term. It is about the somewhat unpredictable, unscheduled. Nobody predicted the shale gas revolution would happen by that research, as an example. Same with nuclear fission, same with solar cells. So the point is, the longer-term work, the federal government has an extreme role and it must involve science, technology and engineering intimately linked and not separated, and that's—the Department of Energy, the way this has been separated, has been a severe hindrance in my view in terms of stovepiping. As I mentioned, even NSF realized in the 1980s through a corporate lab director named Eric Block to create these interdisciplinary centers including engineering research centers so the question to ask is, how are the Energy Innovation Hubs like the Science and Technology Centers and Engineering Research Centers, which is missing in the Office of Science.

Ms. JOHNSON. Thank you. Any other witnesses like to comment on that?

Dr. DEWITTE. I would, please. Thank you.

I think it's one of the interesting things about the commercialization that we're working on towards—with metal fuels specifically and advanced reactors is it opens up the pathway to continuous innovation for improvements that we've discovered along the development pathway already. It's important to never lose sight of that and not to think that something is just ready because it's still at some of those stages that you discover new things to do. Those are still too early for commercial readiness, and it's important to have an awareness on that, and also to maintain that perspective that once you get something ready to go for commercialization, that doesn't mean innovation is done. There's still opportunities and pathways to bridge on that.

Mr. NARAYANAMURTI. May I add?

Ms. JOHNSON. Sure.

Mr. NARAYANAMURTI. So you can argue how far in the innovation chain one should fund, and we can discuss that. This is back to the late stage, and that's a legitimate argument. I would say it depends on the situation.

Ms. JOHNSON. Dr. Venky, the President's budget request declared some research as early stage and therefore worthy of federal support and other activities as later-stage research that should be immediately eliminated given that the private sector is supposedly better equipped to carry this research out. However, the Administration officials recently confirmed to Committee staff that they did not engage with the private sector at all while compiling the budget request to determine what industry would be able to or willing to pick this up. In your experience, are the cuts proposed for the fiscal year 2018 budget research areas that the private sector is willing to simply start funding after the federal government cuts them off?

Mr. NARAYANAMURTI. This is an extremely important question. I actually—I personally feel, I think there is not good data on that anyway, but the private sector today in the United States is just not doing the longer-term work because of the risk involved, and that's one of the reasons in fact because of global competition, other countries are beginning to do more of that because of state support. So the point is, our companies are not doing it, not in every industry. IT is still—I think Google and Microsoft are doing some, which his very good, but the energy case, it's definitely not true.

There is evidence, on the other hand, if government makes the investments, eventually it reaches the private sector as it did for the shale gas and several other cases, but what is really quite important, I think, is there does need to be like our Engineering Centers, our Energy Innovation Hubs, ARPA–E, must involve consultations with the private sector. We do want to have them involved in that discussion so that we can actually think about that. When we made our energy plans in the book which I co-authored with two of my colleagues, we actually interviewed a lot of private sector people where they thought the investment should be made. So I think because they want the long-term investments, so I think we want to involve them in the discussion as well. It has to be a cooperative thing. As I said, technology transfer is a body contact support.

Ms. JOHNSON. Thank you. My time has expired.

Chairman SMITH. Thank you, Ms. Johnson.

The gentleman from California, Mr. Rohrabacher, is recognized.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman, and thank you, Mr. Chairman, for taking the leadership and calling this hearing today. We need to have discussions like this on basics, and your leadership is certainly making sure that we get that type of discussion.

Let me note that to our witness who was mentioning about the—Mr. Sant, who was mentioning about the turning of CO_2 into useful material, and we compare that to what I consider to be sort of an irrational approach to try dealing with CO_2 and just trying to eliminate CO_2. You're suggesting that we actually can use CO_2 in a way that will be beneficial to humankind and making a profit out of extracting it. And let me note that you're talking about cement.

There is a company in my area, Newlight, that has developed a methodology of—and they have a process now working that takes CO_2 out of the air and turns it into plastic, high-quality plastic, and I think that we are going to find with research that instead of going about the regulatory and trying to stamp out the use of CO_2, we're going to find it's much more effective for mankind to find useful purposes for CO_2 that we can actually extract it from the air and we don't have to worry about the debate as to whether CO_2 is a pollutant or not if you actually have people using it for positive ends. So number one, I thank you for your testimony today. I didn't know about your uses that you're suggesting that are available, and I think it deserves a lot of attention. So thank you.

What also deserves attention as far as I'm concerned is the future of nuclear energy in this country, and throughout the world. Nuclear energy had such great—we had such great hopes for it but it should be evident to anyone now that the former light water reactors, the initial move on stage in the nuclear area, is extraordinarily dangerous. We have closed down San Onofre in my area, and rightfully so, because there are dangers involved with light water reactors.

Mr. DeWitte, does your, what you're trying to develop now in the nuclear energy field, does that have the same dangers?

Dr. DEWITTE. No, very different safety profile. It operates truly on natural forces. It's very passive. It has a pressure—basically no pressure operations and so it makes it a very safe profile in terms of what it can do and behave.

Mr. ROHRABACHER. Can it melt down and release radioactivity?

Dr. DEWITTE. Effectively, no.

Mr. ROHRABACHER. So we have the capability now, Mr. Chairman, to actually do this. We've had this capability for a while, and we have instead been for whatever forces at play in our society, we have been channeling resources into developing nuclear power plants that have extreme danger associated with them, and now we should understand, and the testimony today highlights this, that we should focus on our alternatives, making sure the alternative that we have, which is a nuclear energy source for electricity, that is far less dangerous, if not dangerous at all. We should make sure that that comes to play. That's right through this Committee. This Committee will do the things that are necessary to make sure that the next generation of nuclear power, which is safer, that we get into that new generation as soon as possible. And when we're talking about that, as soon as possible.

Dr. DeWitte, do you see the fact that the small-scale programs and perhaps like your own which provide—were provided technical support and lab capabilities, do you think, is that a better way for us to approach this than through large grants through the license to try to move things through the regulatory process?

Dr. DEWITTE. I think in general it has substantial benefits for where the industry is now, and I think it is a better way because I think what we've seen is, we've had very high impacts and high-leverage outcomes from a very small amount of money to date, much more efficiently than you would get with a large cost-share program at this stage. That doesn't mean that you can have those down the road for demonstration-type purposes but I think it's a better use at this stage.

Mr. ROHRABACHER. And one last thing, Mr. Chairman. I think that the—it doesn't really make sense for us to be funding big companies to help them move through the licensing process, which is basically a federal process, so we're giving grants to people to help them deal with the federal agencies and instead we should try to reform the federal agencies so that they don't have these impediments to this type of progress.

Thank you very much again for your leadership, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Rohrabacher, and the gentlewoman from Oregon, Ms. Bonamici, is recognized.

Ms. BONAMICI. Thank you very much, Mr. Chairman, and thank you to the panel for your excellent testimony.

Dr. DeWitte, I want to thank you particularly for mentioning in your testimony NuScale Power, which is of course headquartered in northwest Oregon in the district I'm honored to represent, and also thank you for mentioning the role of the national labs and the Department of Energy in your work over the years. I really appreciate that.

Mr. Kumaraswamy, thank you for talking about energy storage, and your work on energy storage and the potential for modernizing the grid is something that I've had many conversations about back home in Oregon. In your testimony, you say that the national labs through the Department of Energy are doing a great job in advancing the modeling and visualization of benefits that energy storage brings to the grid, and you go on to say that the government should encourage and increase investments in the Department of Energy and national labs to continue this work. Yet we are now looking at the Trump Administration's proposal, which has significant cuts to the Department of Energy. They seem to be ignoring recommendations from industry experts like you. For example, the fiscal year 2018 budget proposes to eliminate the Advanced Modeling Grid Research subprogram that's within the Department of—excuse me—within the Office of Electricity Delivery and Energy Reliability. I know that Administration officials recently confirmed that they did not engage with the private sector at all when determining which Department of Energy R&D programs they would be cutting or eliminating.

So could you comment on what the consequences would be of cutting research and development programs like that one that provide us with the capabilities that you mentioned are so important in upgrading the grid?

Mr. KUMARASWAMY. Sure. I think one of the hallmarks of commercializing new technologies like energy storage and bringing them to market is making sure that the needs of the system and the benefits of the technology can be understood and appreciated by all of the stakeholders, and so just maybe I can offer an example of one of the early instances when we actually deployed energy storage in the marketplace. This happened to be in the mid-Atlantic region of the country in a market called the PJM regional transmission market, and this was largely made possible because of the fact that the market made the need completely known to everybody that was involved in that place, and so you know, it was need that was oriented around frequency management and the role that energy storage could play towards addressing the frequency management issue and provide all of the service and for all of the stakeholders to evaluate those benefits. The tools were available for that. And so I think that's the key part towards commercializing new technologies, and other parts of our electric sector where we don't have organized electric markets like in the PJM market or portions of the Northeast, I think the need still remains pretty obscure.

Ms. BONAMICI. Thank you, and I do want to get to another question. Thank you very much.

Dr. Venky, the Trump Administration released its budget proposal for fiscal year 2018, and the research and development funding levels, as I mentioned for the Department of Energy, are woefully inadequate, and the President said he wants to usher in an era of American energy dominance yet he's simultaneously proposing to cut and, frankly, devastate our energy research enterprise, so that's not the path to a stronger America. It's a path to energy reliance on international, sometimes unstable competitors.

So does the fiscal year budget proposal set us on a path toward energy dominance, and will the private sector be willing and able to fund the research that will no longer be funded if these budget cuts go into effect?

Mr. NARAYANAMURTI. Thank you very much for that question because I think you're right on. In fact, many of the things mentioned including nuclear power at Idaho Nuclear Laboratory or National Nuclear Energy Laboratory, which does a lot of test facilities for many of our things, they come from the so-called applied offices, and these are extremely important test facilities which are vital for the national interest.

Second, in fact, this early-stage technology research is not being done by the private industry. As I said, we do want to involve them. There needs to be cooperative research and development agreements but, in fact, we will become second class from what I see in my role both as Foreign Secretary of the National Academies and continuing looking at what is happening in China and other places. That technology is moving forward, and we need to be at the leading edge.

Ms. BONAMICI. I agree that——

Mr. NARAYANAMURTI. I cannot——

Ms. BONAMICI. Dr. Venky, the energy efficiency and renewable energy would receive a 70 percent cut, and some of the activities will get an 80 percent cut. Oregonians are leading the way with some of these technologies. What would be the consequences of drastically reducing that research and development for U.S. competitiveness in a global economy?

Mr. NARAYANAMURTI. We will not be protecting our future. As an American, I came here during the height of the space race and the role of technology, how important it was. I'm passionate about technology. It is politically agnostic. It really will shape our future. Even electric cars, that horse has run out of the barn. It's only two percent today but longer term people learn to make it cheaper, it'll be much more efficient because the engine is much easier to maintain from simple engineering, the same reason shale revolution happened because natural gas is cleaner and cheaper than coal. So it behooves us—people talked about nuclear. Nuclear is extremely important, and I think for this Committee, it's important to know that no matter what happens, the electricity grid is going to need base power, at least 20 percent base power, so we will have to have it come either some kind of natural gas or nuclear or some other—maybe even coal, clean coal where you capture it. So we want to protect that. It has to be diversified and heterogeneous and we should be advancing the nuclear technology so it becomes safer, more cost-effective, et cetera, and doing that kind of research, I personally think it's still valuable.

Ms. BONAMICI. Thank you, Dr. Venky.

I see my time is expired. Thank you, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Bonamici.

And the gentleman from Texas, Mr. Weber, is recognized.

Mr. WEBER. Thank you, Mr. Chairman.

My goodness. So many questions here.

Dr. Venky, I'm going to come right back to you. You said 20 percent base power backup, whether it's clean coal, whether it's nuclear, whether it's natural gas. How did you get to 20 percent?

Mr. NARAYANAMURTI. I think people have done great work and figured out statistically what will happen so you know that you need some base power. People have—people who know how to manage grids will tell you that you've got to maintain stability have a certain backup of steady power.

Mr. WEBER. That seems low to me because that's one-fifth of the power required.

Mr. NARAYANAMURTI. Somebody may say it might be a little higher. Certainly it's going to be required.

Mr. WEBER. Would you agree that it's better to have more power than less power?

Mr. NARAYANAMURTI. It's always good to have. I believe in safety.

Mr. WEBER. Okay. And you believe in clean coal technology?

Mr. NARAYANAMURTI. If clean coal can be done. So one of the options—technology must provide options, and so when you have one of the areas that long-term federal funding might be valuable is in fact for carbon capture and storage if you can actually make use of the carbon, which is even better. So I actually want to keep those options open including for large investments for certain cases because options is what the technology is about.

Mr. WEBER. Okay. Well, certainly they are, and I would say the higher percentage is the best option there.

Mr. NARAYANAMURTI. And then there are many global countries which are dependent on those. They might have to have some global implications, which might help the overall——

Mr. WEBER. Was it Theodore Roosevelt who said "Speak softly and use nuclear as backup"? I'm just——

Mr. NARAYANAMURTI. Sorry. I get excited.

Mr. WEBER. Just asking.

Mr. NARAYANAMURTI. Yes.

Mr. WEBER. Dr. DeWitte, this question is for you. You were a strong supporter of our nuclear energy legislation, which passed the House three times last Congress—you alluded to that—and again earlier this year as part of the DOE Research Innovation Act.

What could the policy—obviously you're tracking that bill and paying attention. What could the policy in that bill including the construction of that versatile neutron source provide to you and other advanced reactor companies? Would you elaborate on that for us?

Dr. DEWITTE. Absolutely. Thank you for the question. That legislation's incredibly important because it enables—one, it opens up the opportunities and streamlines the processes to work with the national labs and take advantage of their infrastructure and capabilities, and it also, of course, paves the way to provide new capabilities with a versatile neutron source or a fast test reactor, which will accelerate both the development of new fuels and materials so that we can get to market more quickly with these technologies and discover entirely new things that we don't even know about today because we don't have those capabilities that a facility like that would provide.

Mr. WEBER. All while working with the regulatory agency that would be involved in the process——

Dr. DEWITTE. Absolutely.

Mr. WEBER. —which would help expedite that process.

Dr. DEWITTE. And that's critical too because they need to learn from it, and we can all learn together, frankly.

Mr. WEBER. You bet ya. Now, you also mentioned that France and Sweden have done a really good job of reducing their carbon. Do you know percentages and time frames?

Dr. DEWITTE. Generally speaking, France decarbonized pretty substantially in about 15 to 20 years. They effectively went to 80 percent nuclear-based power sources, which reduce their carbon emissions by a commensurate amount. Sweden was a similar time frame and a lesser but a similar impact. It wasn't quite the 80 percent that——

Mr. WEBER. Is France still at 80 percent today?

Dr. DEWITTE. They're a little less just because they haven't been building as many nuclear plants, and unfortunately, they're moving to shut some down, which is a terrible mistake.

Mr. WEBER. Okay. And do you know the grid size per chance of each of those countries?

Dr. DEWITTE. I do not but I know that they are smaller of course than the United States as it is, but off the top of my head, I think the French grid is somewhere slightly smaller than Texas.

Mr. WEBER. Okay. You were vocal about how—is it Oklo? Is that how you say that?

Dr. DEWITTE. Yes, sir.

Mr. WEBER. Oklo is funded through private investment but this is not the norm for innovative nuclear companies. Why did you choose that model?

Dr. DEWITTE. Because that gave us a pathway to get to market quickly. It also gave us a control over our own destiny so we weren't at the whims of either a project manager at some agency or at the political whims depending on what was going on of the government. It gave us insulation from that. It also gave us the ability to focus on what the market wants and not have to cater to what perhaps a grant maker wants.

Mr. WEBER. Refresh my memory. How long has the company been in existence?

Dr. DEWITTE. We started—we launched in 2013, and so it's only been about a little over four years.

Mr. WEBER. And where are you located?

Dr. DEWITTE. We're in Sunnyvale, California.

Mr. WEBER. Sunnyvale, California. Okay.

Mr. Chairman, I'm going to yield back.

Chairman SMITH. Thank you, Mr. Weber.

And the gentleman from California, Mr. McNerney, is recognized for his questions.

Mr. MCNERNEY. Well, I thank the Chairman. It's a good hearing, and I'm enjoying listening to your testimony. I think it's pretty bipartisan, and I look forward to continuing this discussion.

Dr. Venky, would you describe the valley of death for technology and how the government can play a role in that?

Mr. NARAYANAMURTI. So as, you know——

Mr. MCNERNEY. Your microphone.

Mr. NARAYANAMURTI. Sorry. And I'll try to speak more softly. I tend to get excited.

Mr. MCNERNEY. I can understand that.

Mr. NARAYANAMURTI. I would like to say that it's good to have passion, though, to care about it, and I care deeply about us being number one, and my Bell Labs past taught me that. We always have the leading edge.

Mr. MCNERNEY. Valley of death question.

Mr. NARAYANAMURTI. Yes. So very early stages, if we take the transistor, the original transistor was a total clooch. Nobody ever thought you could actually make circuits out of it. So the first phase is to sort of make it something which you can actually make at least a few of. That's the first valley of death, to actually where is this just a good research curiosity and not really any technology. As you learn how to do this, there are of course various stages where you would decide to turn it off. The big valley of death comes a little bit before manufacture because then you have to literally make millions of them and actually invest a lot of money in that. So that—so it's a question of the investment where you go up in scale, so those two valleys of death are particular important, and the first one, there's no clear question that we have a role. That's exactly what ARPA–E or Energy Innovation Hubs, et cetera, do or Engineering Research Centers.

The second one is for the very large issues, and there, you could argue where is the appropriate government's role. At the Harvard Kennedy School, when I first became Director of Science Technology Public Policy program in 2011, we convened a very large group including one of people from industry and a lot of people from government and academia to debate the government's role. It's actually there in that report, and there's not uniform agreement, but everybody agreed for some particular ones, it might be the nuclear case, it might be the carbon capture or storage, but there's a huge public-goods aspect where in fact you must have the options should in case something happen, and coal is an important commodity worldwide, that maybe there is a role. And then should there be some joint thing. Everybody agreed including the industrialists of some important points that things should be steady. We cannot let it be just simply political, i.e. it is a failure.

Second, the companies must have a significant skin in the game. They must have something like 50 percent skin in the game, large skin in the game, and you could find that was the view of this workshop which I held, and of course, some people you may say for some things we don't have a role, the private companies should take it and just spend the money.

Mr. MCNERNEY. Thank you.

Mr. DeWitte, in your opinion, does the fiscal year 2018 budget proposal set us on the path toward energy dominance?

Dr. DEWITTE. I don't think it does. I think there's more we can do, absolutely. But I do think there are some good signs in there, particularly the appropriations for fast test reactor. I'm supportive of that. But I think we need to not lose sight of the fact that if we really care about dominating in the global space, the rest of the world is investing heavily and massively. We cannot lose sight of that. And we have to pay attention to that. But we also have to be focused and mindful about what the markets are wanting and needing and not just in the United States, and that's something that I think sometimes there can be a focus too myopically on. We need to look worldwide and how we can compete globally.

Mr. MCNERNEY. Could you discuss how federal investments in nuclear R&D have paved the way toward your company to succeed?

Dr. DEWITTE. Oh, absolutely. That's a cornerstone upon which we're building and all advanced reactor developers are building. That's an absolute, fundamental necessity that we are thankful was invested in.

Mr. MCNERNEY. Thank you.

Dr. Venky, again, the department of Energy has four Energy Innovation Hubs and they're establishing a fifth one on the cross-cutting issue of the energy-water nexus, which was supported by the last Congress. Do you support the use of—continued use of this model, especially with regard to the energy-water nexus?

Mr. NARAYANAMURTI. Yes. Unlike ARPA–E, which I've looked at in detail in my research, I know the Energy Innovation Hubs, I know the one at Argonne, which is run by George Crabtree in storage, I actually think it's a very important model. These—the full impact will only be known about 10, 15 years down the road but we know from history from what NSF has done and what Department of Defense has done that these will be very valuable. So I—it will have to be a balanced portfolio and there do need to be certain critical areas where you actually combine strengths. Industry should be involved as well as the national laboratories and academia, and I actually think it's a very good model, one of the different ways of doing it.

Mr. MCNERNEY. Thank you.

Mr. Chairman, my time went too fast. I'd like another five minutes.

Chairman SMITH. Thank you, Mr. McNerney.

The gentleman from Illinois, Mr. Hultgren, is recognized.

Mr. HULTGREN. Thank you, Mr. Chairman. Thank you all so much for being here. This is an important hearing, and grateful for your work, and it is so important for us, especially as the Committee continues to look at ways in which the DOE can better assist the private sector as they do what they do best: innovate and bring new products to the market. Seeing firsthand how the national labs work at Fermilab in my district and Argonne just outside of my district, I've been able to see why the labs and our user facilities are often referred to as the crown jewel in our research ecosystem. I was glad to see stable funding for these facilities in the energy and water appropriations bill the Committee just reported, and I'll continue to keep fighting to see this in the final bill as well.

I wanted to address my first question to all of you if any of you have comments on it, and wondered if you could just let us know in what ways did you specifically use federal funded research infrastructure like user facilities at the DOE national labs to develop your technology, and what other facilities should DOE be looking at and how could we change the operating practices of the labs to make them even more accessible to small business and startup developing innovative technologies.

Mr. NARAYANAMURTI. When I was at Bell Labs, we did much of our research work in supporting, for example, light source facilities at Brookhaven National Lab, at Argonne National Laboratory as an example because they are extremely important, and then when I was Vice President, I actually—of Sandia, we actually created photolithography where one can use some of these light sources at Lawrence Berkeley Lab, et cetera, to advance lithography techniques, but those are very—these large facilities including run by the Renewable Energy Laboratory, these are all extremely important including high-performance computing at Fermilab, at Argonne National Laboratory, and we still use them even in academia including the computing facilities. So test facilities are a crucial role and extremely important.

Mr. HULTGREN. Thank you. Anybody else?

Mr. KUMARASWAMY. I could offer a comment. I think one of the key areas that's being pretty helpful from the nation lab side has been looking at the benefits that storage brings to the grid. I think there's significant research that's being done by NREL, by PNNL and Oak Ridge Labs and many of the national labs towards establishing all of the values that energy storage bring to the grid, right, and so I think that's a cornerstone for us to make sure that all of the stakeholders that are involved in some these key decision-making processes are able to appreciate those benefits. Like I mentioned in my testimony, I think it's one where the private sector can significantly benefit from that type of research and computational models that are deployed at the national labs.

Mr. HULTGREN. Dr. DeWitte?

Dr. DEWITTE. I'd be happy to. We've benefited tremendously from the decades of research and development that Argonne led in advanced reactor development, and we're actively working with them now and the capabilities they and Idaho as well as Sandia and others have, and the GAIN program has tremendously help—been tremendously helpful in streamlining access and partnering.

Mr. HULTGREN. I'd like to follow up on that if that's all right, Dr. DeWitte. As you said, Oklo participated in the Gateway for Acceleration and Innovation in Nuclear, or GAIN program, which provides the nuclear community with access to the technical expertise at the national labs in order to commercialize these new technologies. I wonder, do you think these small-scale programs that provide access to technical support and lab capabilities are a better investment than providing large grants to move through the licensing process?

Dr. DEWITTE. In general at this stage in the advanced reactor industry, I do think they are more effective. I think as the industry grows and matures, it might be valuable to revisit that, but the impact that you can get and the return effectively on investment that you can achieve with these small grants that are targeted across a broad spectrum of areas. They yield really high-impact results for very little money. What we've done with a few hundred thousand dollars is frankly been phenomenal in our mind as well as the mind of our investors, very high impact.

Mr. HULTGREN. That's great. Dr. DeWitte, sticking with you, does working with DOE improve or slow down the process necessary for startups like yours to create and implement innovative technologies? What policy changes can be made at DOE to make their engagement with the advanced reactor community more productive?

Dr. DEWITTE. Yeah, I think the answer is, there's benefits and drawbacks at this point, and we're learning. Both parties are learning how to do this better and more efficiently. Contracting structures are being modernized and updated and general interaction mechanisms, and GAIN is very helpful in streamlining that process and identifying issues and helping address them, but the biggest single issue is DOE lacks the sense of urgency that the private sector demands. Unfortunately, in nuclear, we've gotten complacent in the industry like the pace of nuclear compared to the pace of our Silicon Valley peers is order of magnitude different. So we're trying to accelerate that, and DOE needs to, I think, recalibrate that and continue to strive to be more urgent in what they do.

Mr. HULTGREN. Is there anything we can do to help with that?

Dr. DEWITTE. I think one of the issues is, it's been helpful, I think, that you guys have done and will continue to do is through frankly Congressman Weaver's bill to open up access to the national laboratories and be able to partner with them in different ways both as user facilities as well as possible demonstration facilities. That and the impetus that that provides I think is a huge opportunity to help address that issue and otherwise continually revisiting that challenge and seeing what can they do to be faster and more efficient interacting with the private sector. It's just a constant learning process.

Mr. HULTGREN. Great. My time's expired. I'd love to follow up with you, but I need to yield back my time.

Chairman SMITH. Thank you, Mr. Hultgren.

The gentleman from Colorado, Mr. Perlmutter, is recognized.

Mr. PERLMUTTER. Thanks, and Mr. Hultgren on that side and Dr. Foster on this side like to talk about their labs in Illinois. They're like Illinois Chamber of Commerce, okay? So I want to talk about my lab and I want to start with you, Mr. Kumaraswamy, the National Renewable Energy Lab in Colorado, and if you could talk about the way that that lab assists you and others in making sure this technology that is being developed really is valuable to the citizens of this country, so if you could start there, sir?

Mr. KUMARASWAMY. Absolutely. I think they're doing some fantastic work at the National Renewable Energy Laboratory. We are grateful for that. One of the key areas of focus for us at AES is the application of using energy storage for peaking applications, so when we think about the country actually needing significant amounts of generation capacity that would run for a fraction of the time, right? That's what we're talking about when we talk about building new peaking gas plants.

I think that energy storage is an extremely cost-effective alternative for building those peaking gas plants, and that's an area that we have continued to benefit from the NREL type of studies, right, because one of the areas of research that goes on at NREL is to make sure that you actually look at the benefits of using storage for the peaking application and produce those type of high-quality reports based on solid analytics and that helps us pursue these conversations regionally and nationally across many different stakeholders.

Mr. PERLMUTTER. Thank you.

And you know, Dr. Venky, you were talking about clean coal and nuclear and, you know, natural gas, you know, a couple of the others, and I think we need to have a whole diverse approach to our energy production, and so I have a slide up there which shows NREL working on photovoltaics, you know, starting back when the lab started at 76 bucks down to about 30 cents, and there are some tax credits involved, and you know, part of what we're trying to do as a country is to provide a cheaper and better and less polluting as possible. So talk a little bit about that continuum of research.

Mr. NARAYANAMURTI. Thank you very much for that question. Actually, NREL is a laboratory where another postdoc of mine spent significant time looking at their portfolio and analyzing and talking to people.

First I want to mention that we are not given a consistent—somebody asked how can this help. That technology transfer is an important mission and that we are proud of it. So NREL actually developed the first technology which led to First Solar, and First Solar is among the few highly U.S. solar companies which are not in China or Germany. This is extremely important and we should be proud of it, and we should actually celebrate it because it came. The cost of solar of course has been coming down very significantly and producing a lot of jobs. You talk about the jobs, and these jobs will be there no matter what. The energy system is going to be heterogeneous. It is going to require things like solar as well as storage as well as natural gas, and all of it on day one it'll evolve depending on circumstances, on geography, natural resources, et cetera. It's a worldwide issue so us working in this—but however, the way that DOE also needs to make this as an important strategy and can make it simpler but there are certain things the NREL lab directors and the laboratory people should have greater discussion of working across that boundary under some proper guidelines that are open and fair in those matters so sometimes it can be more interfering the way the Department of Energy might run it. Developing a coherent policy there would be valuable. It would help NREL.

Mr. PERLMUTTER. Thank you.

And Dr. Sant, so high school, college, law school, I worked for a precast concrete company, and I was in the laboratory and we'd do the cylinders and then crush them and see how strong they were based on different things that we added. So talk to me a little bit about how strong this CO_2NCRETE using a byproduct that could be a pollutant or could be a real substantial ingredient, tell me how strong this CO_2NCRETE really is.

Mr. SANT. Good question. So in fact, about 65, 70 percent of all concrete in the world that's cast, so to speak, has a strength on the order of, let's say, about 30 megapascals. That's the kind you'd use to build a house. The stuff that we're producing is well within that territory so there's clearly a large accessible market you can reach out to.

I will be careful to point out that we're not trying to look for opportunity to build hundred-story buildings. We're looking for opportunities to build everyday construction, which is really where the large volume of construction is, building as an example. It's also important to point out exactly in that spectrum that there's a unique opportunity here because as I'm sure you're well aware, the construction industry is not really very tolerant of cost escalation. We like the lowest bid, and I think what one of the opportunities that comes about with what we're doing is, we seem to have a real line of sight for being able to produce something that's cost-competitive as is, which is an important part because that's how you start to get penetration and diffusion.

Mr. PERLMUTTER. Thank you, and I yield back to the Chair.

Chairman SMITH. Thank you, Mr. Perlmutter.

Mr. LOUDERMILK. [Presiding] Give me a moment to get prepared after the move here, and now I'll recognize myself for five minutes for questions. That was convenient, wasn't it?

Dr. DeWitte, I'd like to kind of follow up on something that you mentioned when you were having the discussion with Mr. Webster—or Weber. I'm sorry. You talked about stability, and it was the stability and where the government may be, what the reaction of the government is, and the lack of stability going forward when it comes to research and development, and I think that really hits upon a problem that we're facing today because politics is 90 percent emotion, and if we're good, ten percent logic sometimes, and I see you laughing because we're seeing that play out right now on the other side of Capitol.

But historically, we've had agencies and other elements of government that had been that buffer between the whims of politicians and the science of research and development. They were that element that was there that focused on handling the politics on our side but buffering that from the research and development element of our society. The problem I see now from my perspective is that the political drive has filtered into those agencies. There seems to be a political element now within those agencies which we didn't have as much in the past, and some of that comes from talking with some of our research institutions in Georgia.

I recently visited one of our research institutes—well, I visited in the last couple years several of them, and I asked the question, where do we need to go, what do we need to be doing, and there's two things especially when it comes to grants, that we're continually hearing the same concerns from our research institutions is twofold. One is the cost to manage the grant is going up, is extremely high, some up to 20 percent and even more spent on—of the grant money spent just on administration of the grant and reporting, and there's—I'm seeing that that is pretty consistent. And the other is that there's too much emphasis on short-time successes. In other words, there's no room for failure anymore but failure is part of the scientific process. I mean, if it wasn't—if Thomas Edison was receiving a modern-day grant, he wouldn't have invented the light bulb because, as he said, he didn't—his failures were 10,000 ways to prove something didn't work.

So Dr. DeWitte, and I'll expand this out to others on the panel, do you see that? I know you're dealing with private sector and it makes me think that maybe that's some of the reason why you're not going to the government for funding if you would opine on that?

Dr. DEWITTE. Of course. Thank you for the question, and I think that's a very real situation. We recently made some decisions at Oklo with our investors and our executive team not to pursue certain federal opportunities for funding because the costs of managing that were too high. They just simply weren't worth it. And the other part of it is, often those can be targeted in a scope that's, like you said, so risk-averse that it's focusing merely on near-term objectives that really aren't moving the ball forward or they're not even looking at opportunities for finding impact in a market specifically, and as a result, you can kind of just miss the entire objective altogether, and I think that's a very real challenge today.

Mr. LOUDERMILK. Dr. Sant, I noticed you were nodding at part of that. Would you like to——

Mr. SANT. I think that is right. You know, very often I think a lot of goals end up being very narrowly focused, which means that you have to conform to a pretty narrow spectrum of ideas that even potentially look at, and also given the fact that there's limitations in how much risk you can take, that turns out to be problematic, but I think the part which also turns out to the harder is grant timelines turn out to be rather short. I know that most of them are three years, if you're really lucky, 5, and very often sustained work just needs much longer durations than that without an annual review deciding your fate, so to speak.

Mr. LOUDERMILK. Yes, Doctor?

Mr. NARAYANAMURTI. A couple of comments on the same point. The Energy Innovation Hubs, et cetera, Energy Frontier Research Centers, are partially aimed at that longer-term issue, that is, five-year funded or four-year funded, same with the NSF, to encourage that, and some of that needs to happen.

I think appropriate for this Committee is a lot of it's energy. The Department of Energy has been studied a lot including the national labs, which are our crown jewels, and the Senate Committee has made recommendations including how the costs in the DOE might be minimized, et cetera, which would be quite important in tackling the kind of problem you're asking about, in fact, the reporting requirements, et cetera, which would ease some of the burden and get more effect for the actual work being done.

Mr. LOUDERMILK. Well, thank you, and this is something that has been a passion of mine is reforming our grant system to reduce that cost so more of the money will actually go into the research and development and also allow for longer term because, you know, failure is part of scientific research. So thank you all for being here.

At this time the Chair will recognize the gentlewoman from Hawaii, Ms. Hanabusa.

Ms. HANABUSA. Thank you. Thank you very much, Mr. Chairman.

Dr. Venky, I am a great friend of DARPA. I've sat on the Armed Service Committees for years, and DARPA, in my opinion, has been one of the best hidden secrets that the Department of Defense has, especially in terms of its ability to innovate and its structure. Some have described it as 100 geniuses running all over the place with a travel agent kind of moderating, so it doesn't have the usual bureaucratic structure that we think about.

You have testified that you've spent a lot of time looking at the structure of ARPA–E, and as you know, in the Trump budget, his proposed budget, there's only about $20 million and it's really to transition the demise of ARPA–E. Can you first tell me from your perspective and what you know about how ARPA-e operates its importance and its significance as well as the kinds of research that you can point to that have been actually very critical for the Energy Department?

Mr. NARAYANAMURTI. Thank you very much for asking that question. I feel quite passionately about ARPA–E because it's a very important innovation in the Department of Energy. You know, we all value peer review. Peer review is important, but it has its limitation because it leads more to the average, and so ultimately you need program managers who are technically savvy, know the people and the work which is being done, and will consult obviously—you cannot just do it arbitrarily but try to actually pinpoint high risk and high reward where there are actually people who are evaluating the very high-risk part and then they would look at that, take an average, look at that distribution and by judgment make some high risk, and that's what ARPA does too. So it's an important innovation in the management system where you combine some good aspects of peer along with judgment, and especially with regard to high risk.

The other thing which when we looked at many of the awards, we looked at—my postdoc looked at some 4,000 awards which were given by APRA–E. You should remember it's still early. It's only five years old. But what we found was that there was many scientific papers which were published in leading journals like Science and Nature and their impact was similar to that published in the Office of Science and yet there were a large number of patents. There were very few patents from the Office of Science. So that tells me ARPA–E is not being negligent in its science but is also developing new technology, i.e. the other is a missed opportunity. So I'm very positive of that aspect.

And then in its early stage, there are some examples. The National Academies recently issued a report that actually I didn't know that. A colleague of mine at Harvard, Joanna Eisenberg, whom I hired a long time ago, she has developed some very narrow biomaterials which actually now are going to the Nature paper. Another colleague at Advanced Storage, battery flow, which is also scientific as well as leading to a company. So there are different forms here, and the early prognosis is good, and my guess is, it is a very important innovation along with Energy Innovation Hubs and Energy Frontier Research Centers to want to have portfolio.

Ms. HANABUSA. So what do you think is going to take its place, if anything can take its place?

Mr. NARAYANAMURTI. Oh, I hope it does not—I hope in the end—I believe including ARPA–E and much of this work was often a bipartisan. I really believe this should be bipartisan. It is for the country. And that doesn't mean the program manager is always going to choose exactly the right one. That is not—even private people don't do it. And these are risky but there should be some successes, and it should be bipartisan. I hope it really is funded.

Ms. HANABUSA. Mr. DeWitte, when Dr. Venky was speaking, I saw you nodding. Do you have an opinion of ARPA–E?

Dr. DEWITTE. It's an interesting question. I do. I mean, we've supported different, I guess, workshops, if you will, and have been rather impressed by some of the activity that's gone on. However, one of the things that I think—it's an early-stage organization, and it's still growing in a lot of cases and still has a lot of upside. That said, it has struggled, I think, and we've seen certain struggles of it being a little too academic in certain areas. That's not always a bad thing, though. I just think it's a matter of making sure you have an organization that continues to learn because some of these things should be able to afford to fail and learn and grow from that. That's something that we really like to see happen.

Ms. HANABUSA. Thank you.

Mr. Chair, I yield back.

Chairman SMITH. Thank you, Ms. Hanabusa.

And the gentleman from Louisiana, Mr. Higgins, is recognized for his questions.

Mr. HIGGINS. Thank you, Mr. Chairman.

Gentlemen, thank you for appearing before this full Committee. Your combined IQ is frighteningly high and a welcome transition from some of the things we witness in Congress.

Representing a state that is recognized as perhaps the Nation's leader in the oil and gas industry, I witnessed regulatory overreach over the last decade to push the American oil and gas industry to the shores of other countries, and considering the totality of circumstance of the world's ecology, my personal opinion is that it's a psychologically unsound logic.

So Mr. DeWitte, my question is for you, sir, regarding nuclear technology. Nuclear energy is one of the most heavily regulate industries in the United States, and we must balance the benefits of nuclear energy with potential safety risks and ecological concerns. These regulations can impede the potential for the export of U.S. nuclear technology but we must recognize that a high regulatory burden on exports in the United States could work against nuclear safety worldwide and security goals if it allows less regulated technologies form countries like Russia and China to reach new nuclear markers. What types of regulations do you believe, sir, are unnecessarily holding back the export of U.S. nuclear technology?

Dr. DEWITTE. Thank you very much for the question. I'm very passionate about this issue because it's a huge hindrance to global leadership in nuclear and it's something that we really actively as a country need to reevaluate because, like you said, our barriers we're self-imposing are preventing us from being a massive world player that we should be here but also ceding the opportunities to frankly less mature and less safe and less beneficial competitors, and the reality is, we need to reevaluate that at the DOE level as well as the Department of Commerce, the NRC and the Department of State.

In the last ten years or so, there's been significant changes to the rules about export controls in nuclear that have been very detrimental. They've gone in the wrong direction. The expectations that were set in terms of exporting reactors to, for example, the UAE when we were negotiating those deals 8 or so years ago were misguided and have set the wrong expectations and the wrong standards that aren't aligned with what frankly the U.S.'s goal and the global goals for nuclear deployment should be. We need to reevaluate those and we have to do it now because it's affecting us today.

Mr. HIGGINS. Thank you for that answer. I concur. Would you have specific recommendations perhaps you could provide this full Committee in writing over the course of the next month or so whereby we may consider your recommendations, sir——

Dr. DEWITTE. I would be——

Mr. HIGGINS. —as we attempt in a bipartisan manner to consider of course ecological concerns of our planet while at the same time recognizing the superiority of clean United States technology regarding energy development?

Dr. DEWITTE. I would be happy to. American nuclear technology is the best so I'd be happy to do that.

Mr. HIGGINS. One more brief question, if I may. The Department of Energy has recently made improvements to its Tech to Market and Technology Transitions programs. However, many companies still struggle with tech transfer contracting procedures that can take up to a year to complete. From your perspective, how could the federal government streamline public-private partnerships and ease access to taxpayer-supported research?

Dr. DEWITTE. I'll take a first go at that. I think one of the issues that we've seen is the fact that the contracting structures and the liability bases that the labs are effectively using to make their determinations are out of touch with what the objectives of the national labs really should be to the point that it's—they're afraid to do anything. We need to reevaluate that. It gets to a more fundamental question I think is, what are the contracting structures for the operators of the national labs? Bell Labs operated Sandia Labs in a beautiful way and in a way that centered around advancing the national interest and achieving and growing national excellence. I think we've lost that today. I think it's time to reevaluate some of that so we can get back to what the core mission and the core capabilities of the labs are. I think that's one of the starting points, and there'd be some others, but for the sake of time, I'd be happy to defer those to writing.

Mr. HIGGINS. Thank you. I would appreciate that. I believe your colleague has a comment.

Mr. NARAYANAMURTI. I want to just second this aspect here. It is very important that the DOE is now actually having a technology transfer lab and a lot of it can be done at the laboratory level, people that understand the technology closely. That was our finding with NREL so I think reform and really recognizing strategically would add greatly and improve our technology transfer.

Mr. HIGGINS. Thank you, sir. Gentlemen, thank you.

Mr. Chairman, I yield back.

Chairman SMITH. Thank you, Mr. Higgins.

And the gentleman from New York, Mr. Tonko, is recognized.

Mr. TONKO. Thank you, Mr. Chair, and thank you to all of our witnesses for participating in a very interesting hearing.

The only way we are going to meet our energy challenges is through investments in research and development. We cannot lose sight of the vital role that government plays in innovation. The federal government must be an active partner with our universities and certainly with our private sector.

Having an R&D portfolio that covers the spectrum from basic sciences to technology development, testing and deployment greatly augments the work being done by the private sector and in the university community, and sustained support of these efforts is essential to lowering costs and improving performance of our energy technologies.

Dr. Sant, can you tell us a little bit about the role federal agencies have played in supporting your efforts?

Mr. SANT. Of course. Happy to answer. So federal agencies, like I said, the Department of Transportation, the National Science Foundation and the Department of Energy have all funded our work. It's all been funded at early stage. We're in a university. However, the important thing to point out is that we've been able to access support from each of these agencies that is really, really very strategic. It's come together to be able to address questions that are very narrow but we're very interested in. For example, we're interested in trying to understand how to really take building materials, which literally eat carbon dioxide. There's two parts to this. So of course while we look at the basic to the applied continuum, while we're working at the basic part, we need support going all the way into the applied end of the spectrum, and the reason that I say this is, while we do things in a laboratory and it's easy often to realize successes, the challenge that you often run into is that as you start to scale up, there are things that don't work, which require you to go back to the lab, and so you need this pathway where you can stage research and funding dollars to be able to go across the entire pathway, and that's how you succeed in taking ideas and converting them into innovation and then translating them into technology.

I think this is especially important to point out with conventional industries, for example, like the energy sector, the construction sector, which have very limited risk appetites, so to speak, and that's why it's very necessary for the government to underwrite a larger portion of the R&D pathway than would be typical, for example, let's say, in the semiconductor space, and hence I think it's extremely strategic that agencies keep this in mind as funding decisions are made because it has implications on timeline and how you focus investment to go from ideas to wins that you can translate globally.

Mr. TONKO. Thank you. And you talked about that carbon footprint in your comments slightly. The DOE's Office of Fossil Energy——

Mr. SANT. Yes.

Mr. TONKO. —has been working to reduce greenhouse gas emissions through their fossil energy research, and you've been involved in that somewhat?

Mr. SANT. Yes, so we are actually funded at this point through the National Energy Technology Laboratory.

Mr. TONKO. Wonderful, and certainly I agree that across the field we need to develop technologies to reduce our carbon footprint, which is what I'm very proud of in terms of supporting a bill to make advanced gas turbines more efficient. The gas turbine R&D bill that I'm carrying with a fellow Republican with authorize DOE's Office of Fossil Energy to carry out a multiyear, multiphase R&D program to improve the efficiency of gas turbines used in our power generation systems and to identify the technologies that ultimately will lead to gas turbine combined cycle efficiency of 67 percent, what might seem just like a trivial improvement but tremendously important in terms of electrons saved.

If Members of Congress are going to claim to support an all-of-the-above energy philosophy, then we need to support and fund an all-of-the-above research strategy to complement it. That means supporting robust funding for EERE and certainly for ARPA–E.

Dr. Venky, we know that ARPA–E plays a critical role in expanding our portfolio of innovation programs and lowering the risk on projects that would not be supported by the private sector. Can you give some examples of how the products, processes, fuels or technologies that have been developed as a result of ARPA–E's investments are changing our energy system and addressing the challenges we face?

Mr. NARAYANAMURTI. As I mentioned to another question from the Congresswoman from Hawaii, the National Academies recently issued a study. Of course, ARPA–E is still in the early stages, only four years old or something like that, but there are several examples we see highlighted. One was actually from Harvard with the slip-on technology, and I know of work that is done at Santa Barbara, Gallium Electronics, which has blossomed significantly, and as I mentioned in my previous response, they also have been doing some very good science. It's really a missed opportunity if you don't do them together. It's really—there's so many good examples. They're the right track, and I will hasten to bet that ten years from now with the fullness of time, we're going to have lots of examples because there's both good science being done and patents being created.

Mr. TONKO. Thank you. Thank you very much.

I'm out of time, so Mr. Chair, I yield back.

Chairman SMITH. Thank you, Mr. Tonko.

The gentleman from Texas, Mr. Babin, is recognized.

Mr. BABIN. Thank you very much, Mr. Chairman, and I appreciate all you witnesses being here today.

Dr. Sant, I would like to ask you a couple of questions if you don't mind. Can you explain the upcycling process in layman's terms?

Mr. SANT. Sure.

Mr. BABIN. And how the process differs from traditional approaches to carbon utilization if you don't mind?

Mr. SANT. Sure. So in a brief sentence, we can define upcycling as beneficially utilizing a waste so it's this idea of converting trash into treasure. We combust fossil fuels, we emit carbon dioxide from the stack. The work that we're focused on is really trying to take that carbon dioxide and reutilize it. Now, the way we reutilize it is, we use this compound called calcium hydroxide, which you produce, for example, by either burning limestone and emitting CO_2 and so hence it lets you keep the same mineralized CO_2 within a loop so that's how you reuse it. The other way you can actually produce calcium hydroxide is by using alkaline waste that you get from industries like slags and fly ash as an example and extracting calcium and magnesium ions out of those. So what you're really looking at doing is creating, let's say, a chemical sponge to soak carbon dioxide, and over the course of that reaction, you undergo a transformation to produce limestone.

Now, an important thing to point out about this upcycling process is the reason it turns out to be very attractive is it gives you a strategy for both avoiding and reducing the amount of carbon dioxide you would produce otherwise by producing traditional ordinary Portland cement. That's an important thing because what you can do with this approach is, you can create an offtake partnership so essentially a power producer can work alongside a cement producer since both of them emit CO_2 but one produces a material that can potentially soak up CO_2. You let these industries actually start to work together.

I think the sector-level synergies are extremely important to catalyze because as you go forward and we look at this idea of trying to create new synergies and new efficiencies in the energy space, we need to get industries that were otherwise not, let's say, correlated with each other, interacting with each other.

Mr. BABIN. All right. What is—if this was a widely deployed process throughout the land, what would be the impact? Would it be dramatic? Would it be a partial impact? Please let me know what you think there.

Mr. SANT. Sure. That's a very good question actually. So if we assume global scaling of some of these processes which utilize carbon dioxide, landscape analysis that we have done and others have done shows that you can basically use up to about ten percent of global CO_2 emissions, right, so it's on the order of let's say three or four billion tons. Now, ten percent seems like a small number. It's actually a really important number because what you're really showing is a value system and a pathway to creating value that you cannot utilize otherwise.

So when you look at concrete, which is one way that you can utilize CO_2, or plastic, which is another way to do it, by creating value, you show that there's opportunity where there was none, and I think that's something which is important, for example, for industry to be able to see because we are very often used to seeing carbon dioxide as a negative. What we're trying to do is really create this positive perception which is associated with revenue generation because that helps you really create longer-term pathways which are associated with more risk which do of course render a more permanent solution but you want to get points up on the board before you go for the big ones every time.

Mr. BABIN. Okay. And then just to maybe enhance what you just said, in what way can your upcycling technology potentially surpass more traditional CO_2 utilization such as through the use of captured carbon for enhanced oil recovery, for example?

Mr. SANT. So one of the really important things about the work that we're doing is that we can utilize flue gas without any preprocessing or without any post-processing, so an important aspect as to what really drives up the cost that's associated with carbon capture as an example utilization is lots of these processes require enriched or purified CO_2. The way our process is designed is we can basically take flue gas that comes out of a stack in a power plant or in a cement plant or a petrochemical facility and use it directly as a reagent in our chemical process. I think this is an extremely important point because the cost of capture is really a limiting step at this point, and if you can start to utilize flue gas without a capture cost, now you really start to see some economic viability that can start to model these processes.

Mr. BABIN. Okay. Thank you very much, and I yield back, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Babin.

And the gentleman from Virginia, Mr. Beyer, is recognized.

Mr. BEYER. Thank you, Mr. Chairman, very much.

Dr. DeWitte, I was fascinated by all your conversation, your work on the small nuclear reactors. I was sitting next to Congresswoman Jackie Rosen from Nevada, and she was sort of—I don't want to mischaracterize but instantaneously anxious about the fuel. So I pointed out the first page of your testimony about how you're reusing fuels from some of the other places including the plutonium. At the end of the day, is storage still a problem or an issue that has to be solved with respect to the small nuclear reactors?

Dr. DEWITTE. In terms of waste storage?

Mr. BEYER. Yes.

Dr. DEWITTE. It's a different problem but it's a very much smaller problem in the sense that the output effectively is going to be something that's radioactive for nominally 300 years at most, at most, and a very small volume of what you would produce otherwise. So really, what we're doing today is we're taking fuel. We're only extracting about one percent of the total energy content in that fuel and then we're putting it—trying to dispose of it. What we're trying—that's what we're doing today. What we're trying to do and what other fast reactors can do is take that and extract basically the rest of that 99 percent energy content out. Now, there's still some radioactive material at the end of the day but you can safely store that. It only needs to last for a couple hundred years before it decays away to nothing. At that point you can have it vitrified. You can make glasses out of that you could drink out of, in fact, so it would be perfectly safe. It's a very manageable problem at that point.

Mr. BEYER. The sense I'm getting from your testimony is that the development of your fast reactor technology to scale could solve a lot of the disposal problems of the bigger reactors that we have already.

Dr. DEWITTE. Absolutely. It changes it from a problem to really an opportunity because now you have a bunch of fuel that we could power the United States on for hundreds of years, like all of the United States power needs, so it's a phenomenal opportunity.

Mr. BEYER. You talked a little bit I know before about the Nuclear Regulatory Commission and they've been adapting to small rather than big. How about the insurance companies, you know, the liability and—are they still treating you like Three Mile Island or——

Dr. DEWITTE. That's an excellent question, and I think it's a question that needs to become more prevalent and mature going forward. There's a lot of differences between small reactors and advanced reactors in terms of what the potential risks are, the potential consequences, and therefore what the liability should be and what the insurance capabilities need to be, and generally it's a much smaller footprint, it's a much smaller need, so the current framework in some ways and in some cases is kind of—it's inefficient. It's not set to actual technology capabilities today, and that needs to modernize, and I think that conversation in general needs to pick up. Frankly, now is the time to do that.

Mr. BEYER. Thank you very much.

Mr. Kumaraswamy, I've had many conversations with folks in your business about the exciting role that batteries can play, especially when you think about power plants as a step by step. Do you see this as also promoting clean energy, reducing emissions, having a role in a 21st century electric grid?

Mr. KUMARASWAMY. Absolutely. I think the way we see is that it gives us the capability to recouple the demand and the supply piece, which gives us transformational capabilities, right, and so again, like I said, it has significant potential for you to think about increasing the efficiency that we operate the existing system with, both in the general and the transformation and distribution side. It's a question that we get asked all the time about whether storage or generation or transmission or distribution, and it's all of the above really, right, because it is able to play into all of those areas that we have traditionally assumed to be pretty bifurcated. And like I said previously, when we are faced with a future where the baseload generation plants are facing retirement decisions and we're continuing to add more renewable sources into the grid, there's a need that you have to add more peaking capacity into the grid, and the most cost-effective way of providing the peaking capacity is through deployment of large-scale energy storage.

Mr. BEYER. Are you working with Elon Musk and all these electric cars and steering wheels—cars without steering wheels, things like that?

Mr. KUMARASWAMY. I buy some of the products.

Mr. BEYER. Dr. Venky, you know, one of the criticisms that's often come from my friends on the other side about Department of

Energy was picking winners and losers and interfering with the free market by crowding out private investment, but you worked at Bell Labs, you worked at Sandia National Laboratory, how do you perceive this or what's been your experience about the federal government having a role in these things?

Mr. NARAYANAMURTI. Well, I—first of all, there are many forms in which you can actually interact with industry. With the early stages, take ARPA–E. They are having wide solicitations. They ask for a lot of different proposals. They get reviews of them, and obviously some people get selected, some don't. This is true for even academia. So it's a very quite robust process but your risk case is not going to be perfect. In a sense, you must pick winners and losers, so to speak, and hopefully the ARPA–E program managers are wise enough that—and long term of course—so I just don't see that argument at all as long as the process is fair and this is how it is done. It's always a judgment question. This is true. I complain when my grant is not approved. Was it unfair to me? You know, as long as the process was robust.

So the other feature which I think is important is there are many different kinds. There can be joint agreements with industry where they're actually putting skin in the game and say we want your help. There's cooperative research and development agreements. So we should allow for different forms and different industries but the early-stage part, I don't see that as an issue. Even in the very long range, as long as we have an open process and we have this thing properly documented, that would be great.

And the Loan Guarantee program has been under debate. That's the one where you can actually have a serious argument. It of course has to be done with much greater care because the amount of investment is huge.

Mr. BEYER. Thank you, Doctor, very much.

Thanks, Mr. Chairman.

Chairman SMITH. Thank you, Mr. Beyer.

And the gentleman from Kansas, Mr. Marshall, is recognized for his questions.

Mr. MARSHALL. Thank you, Mr. Chairman. My first question's for Dr. Sant. Dr. Sant, Chairman Smith and I had the opportunity to recently see what we believe is the country's largest 3D printer at Wichita State University, and one of the technologies they showed us was additive manufacturing to the 3D printing, and they described it as a potential game changer for manufacturing. Can you talk a little bit about how you think they could use this additive technology to manufacturing? Would it help you scale up your technology?

Mr. SANT. Yes. So actually we are working on additive manufacturing, specifically related to construction systems. In fact, there's great opportunities. An important part of what we're working on, and I think we've stumbled into this but it's turned out to be a major opportunity. The material that we're working with is much easier and must better suited for additive manufacturing than traditional concrete, and this turns out to be quite an advantage for a variety of reasons. So traditional concrete that amongst the poorest what you call strength-to-weight ratios of synthetic materials, using additive manufacturing components lets you use materials a lot more effectively so if you imagine that you can produce structural elements—beams, columns and slabs—and take them out to a construction site and start to assemble them kind of like a large Lego set that has major impacts on the construction sector because it really starts to improve construction productivity. If you can imagine—very often we heard of construction projects being delayed. If you can imagine you're taking prebuilt sections out on site and starting to assemble those, that's a much more efficient process to be able to construct with much more efficient systems so additive manufacturing clearly in our minds is the path forward as far as construction goes.

Mr. MARSHALL. Well, thanks, and what I'm going to always remember is they showed us the structure of wings for airplanes. They of course manufacture lots of airplane stuff in Wichita, and they basically told the computer to make it stronger and it ended up looking like a bird's wing and just the micro structure of it.

I'll go to Mr. Kumaraswamy next. Battery storage is a huge issue obviously. A third of the energy in Kansas is now generated via wind energy, and the storage of that wind energy is always the challenge, and we hope to—we are already an energy exporter from Kansas, so just talk a little bit about your technology. As I understand and read your process, it's a—your batteries are side to side to side. What's the future look like for battery storage or what's your vision and where do you think we're going with this?

Mr. KUMARASWAMY. Sure. That's a great question. We—the product that we have, which is called Advancion, is an energy storage platform. We are not a battery manufacturer company so we actually buy batteries from many different certified suppliers. It's a platform that we have that we have developed that actually has some unique advantages in terms of serving the grid. It's pretty modular in terms of the architecture that we have come up with, and again, we are in a leadership position in deploying energy storage solutions both nationally in the United States and globally.

For the specific issue that you mentioned, there are significant applications of energy storage, so if you have intermittent variable generation, one of the issues that you have is making sure that the time in which the generation actually is produced aligns with the peak times in which the demand occurs on the grid condition, right? And so oftentimes what we see with both wind and solar generation is that there's a misalignment of when the generation production happens and when the demand for electricity happens in the late evening hours when people actually come back home, and that's one of the applications of energy storage is the ability to actually move all of the generation that's happening in the early afternoon periods towards the early evening periods when the demand hits its peak, and we are currently deploying some of these longer-duration storage projects also.

We have a project that's currently under construction in California. It's 100-megawatt, 400-megawatt-hour energy storage project so it's 100 megawatt, 4 hours of duration project. So think about moving your generation from the 4 p.m. hour to the 8 p.m. hour. That can be completely done, and we think that it's the most cost-effective way in which we can accomplish that objective.

Mr. MARSHALL. Are these still just commercial batteries side to side to side to side or what's that look like?

Mr. KUMARASWAMY. It's lithium-ion batteries. The Advancion platform that I mentioned is largely agnostic to technology. We basically look at whatever technology makes the most amount of sense for our customers, which are utilities in most cases, but to date what we have found is that lithium ion has the best amount of efficiency and cost-effectiveness right now, and as far as we can see, that still applies at least in the next 2- to three-year time frame with the synergies that lithium-ion technology has with the transportation sector on the electric vehicle side. It still continues to be the technology that we are anticipating will provide the characteristics that can be helpful for the grid.

Mr. MARSHALL. Thank you. I wanted to talk nuclear engineering but I'm out of time. Thank you, and I yield back.

Chairman SMITH. Thank you, Mr. Marshall.

And the gentleman from Florida, Mr. Crist, thank you for your patience.

Mr. CRIST. Not at all. Thank you, Mr. Chairman.

And thank you to all the panelists for being here today to share your unique perspectives on energy technology research and development.

I'm from Florida, the Sunshine State, where our energy is our economy and our environment. Protecting our natural resources is of the utmost importance to myself and the constituents I represent. That's why I'm extremely interested in increasing the use of clean energy to meet our environmental needs, particularly in the area of solar.

Mr. Kumaraswamy, from my understanding, better energy storage technology could help the United States to greatly expand our portfolio of zero-emission energy sources. Can you discuss how energy storage can be combined with renewables like solar and wind to help reach our clean energy and environmental goals?

Mr. KUMARASWAMY. Absolutely. Just also as a note that the United States actually has a leadership position in terms of deployment of grid-scale energy storage. I think as of Bloomberg data that's a couple of months old right now, we have more than 30 to 40 percent of the global energy storage installations across the whole world. So it's something that we should be proud of.

And energy storage, again, you know, it's one of those things where there's significant potential for using that along with renewable energy technologies like solar and wind. AES actually is currently also developing a project in Kauai at the end of Hawaii which is a combined solar plus storage project, right, and so it's a combination of solar technology and battery-based energy storage technology to make sure that you almost create a firm block of power that can be developed to the grid. Like I was mentioning previously, one of the things that you had to worry about if you have intermittent variable generation is the misalignment of when the generation occurs in the system and when the demand actually peaks, and storage is the glue that can help you bridge that gap that you have in the system.

And the other issue is also that in several cases what we see is that when you keep adding more variable generation to the system, there's a tendency for us to think about adding more peaking gas plants to balance all of the generation. In our view, it's not the most prudent choice to add capacity into the grid that runs for like a fraction of the year, right? If you think about peaking gas plants that we have across the country, the average capacity factor of that is something like 5 to six percent of the year. In an economy where we're moving towards shared services in pretty much every commodity that we think about. If we think about Air BnB on the hotel side or Uber for the transportation side, we are thinking about shared services, right? So in that economy, we think that if you make multibillion-dollar investments into peaking gas plants but run for a fraction of the year, that's just not in the best interest of ratepayers, and I think storage would be a lost more cost-effective in performing that function.

Mr. CRIST. Is the same type of energy storage equally suited to grids powered by different energy sources, wind versus solar versus natural gas versus coal-fired power plants or would it make more sense to use several different types of energy storage?

Mr. KUMARASWAMY. The storage itself is agnostic again to the type of generation that you have. It just gives you the capability to store energy and release it at a later point in time, right? And so it's agnostic to whether it's coal or natural gas or any other source that you actually use to charge but again, in many markets that we have gone into, we have seen significant benefits including environmental benefits that additional storage brings to the grid.

Part of the reason is also that it lets you optimize the existing portfolio of generation plants to operate more efficiently, right, because as the demand keeps changing, power plants keep moving up and down, basically they're consuming more fuel or less fuel to balance the needs of the grid, right? If you add storage into the system, the storage actually is able to take up the job of moving up and down to balance the demand conditions, letting the existing power plants operate much more efficiently which means that they're running at better heat ray blocks, at better efficiency blocks, which means that their emissions go down, so that's a significant benefit that we have seen in some of these markets.

Mr. CRIST. Well, thank you. It's clear to me that we need greater energy storage in America. What can the federal government, Congress in particular, do to help encourage additional research and development in this field, in your view?

Mr. KUMARASWAMY. Like I mentioned in my testimony, I think on the lithium-ion side of the house, I think the technology is stable. There's a lot of private capital that's chasing more innovation like improving cell density and production and costs and all of that, so I think private capital will continue to push that forward.

There is a significant role for us to make investments in early-stage R&D on other promising battery chemistries that have greater potential in the near future like extending the duration in which you can actually storage energy, right? So I think that's an area that the government should continue to focus on.

And I think the second and most important area is also that we want greater recognition of the benefits that storage brings to the grid, particularly for applications like peaking capacity. When we go and talk to regulators across the country, it's one of those common questions that we bring up all the time, which is how does it compare with a peaking gas plant, and it's an apples-to-oranges type of comparison because a peaking gas plant has to be turned on to provide a service and then it shuts off, and when it shuts off, it can't provide a service. In contrast, energy storage is a 24 by 7 resource. It's connected to the grid all the time. So when you need that peaking capacity, it's able to discharge and provide you that capacity, and for the remainder of the day or the remainder of the time, it's actually able to provide for other ancillary services that are needed for the grid.

And so the other area of focus should be continued investments in the national labs to make sure that there's awareness of all of the benefits that storage brings to the grid.

Mr. CRIST. Thank you. Thank you very much, Mr. Chairman. I yield back.

Chairman SMITH. Okay. Thank you, Mr. Crist.

And again, thank you all, our experts, for being here today. The testimony to me was very informative and very valuable to us.

The record will stay open for a couple of weeks in case Members have additional written questions they want to submit, and that concludes our business, and we stand adjourned.

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

Appendix I

ANSWERS TO POST-HEARING QUESTIONS

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Venky Narayanamurti

HOUSE COMMTITEE ON SCIENCE, SPACE, AND TECHNOLOGY

"Energy Innovation: Letting Technology Lead"

Dr. Venky Narayanamurti, Benjamin Peirce Research Professor of Technology and Public Policy, John A. Paulson School of Engineering and Applied Sciences, Harvard University

Question submitted by Rep. Jacky Rosen (D-NV)

1. We have representatives from tremendously innovative companies here today, so I am sure that you have all had no problem attracting the best and the brightest to come work for you. As a former computer scientist and systems analyst, I know that the best facilities and the best companies attract the best talent. When I was choosing where to work, I would go where I had the greatest opportunities to do interesting work and make an impact. That's true in the private sector, but it's also true when it comes to federally-funded research. If the United States does not adequately fund scientific infrastructure and provide strong support to researchers, we will lose out on bringing the best and brightest minds and *keeping* our best and brightest minds here in the U.S. to do research that benefits all Americans.

   We can be sure that this lack of forward thinking in the research arena will place us behind globally and put our national and homeland security at risk. Not every research project will have "profitable" results but may nonetheless be important to overall security or energy challenges. That is why I believe we must continue our robust support for energy research and the facilities that attract key talent to our country.

   a. Dr. Venky, can you talk about the importance of investment in federal research, federal facilities, and particularly Department of Energy facilities, as it relates to U.S. competitiveness on the global stage?

As I detailed in my oral remarks and written testimony, federal investment in Research & Development (R&D) particularly the DOE, is very important not only to advance the frontiers of science, but also the frontiers of technology. The US DOE is one of the primary funders of research in physical sciences and engineering and the host of major experimental materials characterization and test facilities housed in its 17 national laboratories. These facilities not only push the frontiers of research, but are widely utilized by academicians, other federal agencies, and industry for evaluation and testing purposes. These include synchrotron based light sources at SLAC and Argonne, Neutrons at Oak Ridge, wind tunnels and biofuels and solar test facilities at NREL and nuclear facilities at INEL.

Having new instruments is key to advancing research knowledge and we face strong global competition in this area. In my dealings with foreign countries I have observed many facilities in Europe, for example CERN ,Fusion facility in France, and state of the art light source facilities in Germany and Japan. China , Japan and Germany have made major investments in targeted areas of R&D in myriads of emerging renewable technologies . like battery and EV technology and are pushing the envelope in terms of materials characterization and testing including supercomputing. Some of the most advanced super computers are now produced in China and Japan. If we want to remain at the forefront of R&D we have to continuously upgrade the research infrastructure, especially instrumentation facilities. China's investment in R&D is near 3%of GDP and is emerging as one of the key producers of research papers and new technology.

HOUSE COMMTITEE ON SCIENCE, SPACE, AND TECHNOLOGY
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Question submitted by Rep. Dan Lipinski (D-IL)

2. If DOE were to shift to only funding "basic" or "early stage" research, as the administration has suggested, this would likely mean abandoning or scaling back decades of investment in programs that focus on applied research and commercialization such as SBIR, Energy I-Corps, the Energy Innovation Hubs, and the Federal Laboratory Consortium for Tech Transfer, programs that have traditionally enjoyed strong bipartisan support.
    a. Can you speculate what the impact of this change would be on DOE's ability to carry out its mission and on the industries that rely on innovations developed at DOE to produce new products and create jobs?

Again, I refer you to my written testimony and some of my earlier remarks. An important part of DOE's mission is technology transfer and as I often say, technology transfer is a body-contact sport. Private industry can only utilize government funded R&D through a continuous stream of mutual collaboration, partnerships and interaction. Recent DOE constructs such as energy innovation hubs, ARPA-E, and organizational efforts(single undersecretary for Science and Energy) to facilitate technology transfer in my view, are vital if we are ever to reap the full benefits of government supported R&D. In my written testimony I gave examples of independent NRC studies of the DOE Applied Offices and their impact in creating technologies and the new job creating industries.

The level of industry participation should obviously increase with the maturation of technology. I believe strong arguments can be made for government's role in late stage commercialization in very selected areas where the huge capital costs, strong "Public Goods/health and environment benefits", or necessary safety regulations necessitates such support , e.g technology for carbon capture and storage from coal plants, or further development of Nuclear Power among others.

At the Harvard Kennedy School I organized a workshop 2011 which brought leaders from academia, the government and industry to debate this question. This workshop highlighted the key conditions necessary for success in.You can find a comprehensive discussion of this issue at this
link: http://www.belfercenter.org/publication/transforming-energy-economy-options-accelerating-commercialization-advanced-energy

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