ADVANCING SOLAR ENERGY TECHNOLOGY: RESEARCH TRUMPS DEPLOYMENT

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FIFTEENTH CONGRESS

FIRST SESSION

DECEMBER 13, 2017

Serial No. 115–43

Printed for the use of the Committee on Science, Space, and Technology

Available via the World Wide Web: http://science.house.gov

U.S. GOVERNMENT PUBLISHING OFFICE
28–413PDF WASHINGTON : 2018

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December 13, 2017

ADVANCING SOLAR ENERGY TECHNOLOGY: RESEARCH TRUMPS DEPLOYMENT

WEDNESDAY, DECEMBER 13, 2017

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

The Subcommittee met, pursuant to call, at 2:09 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Randy Weber [Chairman of the Subcommittee] 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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Subcommittee on Energy

Advancing Solar Energy Technology: Research Trumps Deployment

Wednesday, December 13, 2017
2:00 p.m.
2318 Rayburn House Office Building

Witnesses

Mr. Daniel Simmons, Principal Deputy Assistant Secretary, Office of Energy Efficiency and Renewable Energy, US Department of Energy

Dr. Martin Keller, Director, National Renewable Energy Laboratory

Dr. Steve Eglash, Executive Director, Strategic Research Initiatives, Computer Science for Stanford University

Mr. Kenny Stein, Director of Policy, Institute for Energy Research

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

HEARING CHARTER

December 13, 2017

TO: Members, Subcommittee on Energy

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

SUBJECT: Energy Subcommittee hearing: "Advancing Solar Energy Technology: Research Trumps Deployment"

The Subcommittee on Energy will hold a hearing titled *Advancing Solar Energy Technology: Research Trumps Deployment* on Wednesday, December 13, 2017, at 2:00 p.m. in Room 2318 of the Rayburn House Office Building.

Hearing Purpose:

The purpose of this hearing is to examine advancements in solar energy technology and the Department of Energy's (DOE) reported effort to refocus solar energy funding towards early-stage research, including the Solar Energy Technologies Office multi-year program involving early-stage research on photovoltaics (PV) technology, grid integration, PV materials, and concentrating solar thermal power. Additionally, this hearing will discuss the National Renewable Energy Laboratory's (NREL) basic and early-stage research initiatives focused on improving solar energy technology.

Witness List

- **Mr. Daniel Simmons**, Principal Deputy Assistant Secretary, Office of Energy Efficiency and Renewable Energy, US Department of Energy
- **Dr. Martin Keller**, Director, National Renewable Energy Laboratory
- **Dr. Steve Eglash**, Executive Director, Strategic Research Initiatives, Computer Science for Stanford University
- **Mr. Kenny Stein**, Director of Policy, Institute for Energy Research

Staff Contact

For questions related to the hearing, please contact Jimmy Ward of the Majority Staff at 202-225-0222.

Chairman WEBER. The Subcommittee on Energy will come to order. Without objection, the Chair is authorized to declare recesses of the Subcommittee at any time. Welcome to today's hearing entitled, "Advancing the Solar Energy: Research Trumps Deployment." I recognize myself for five minutes for an opening statement.

Good morning. I appreciate you all being here. Today we will examine the status of U.S. research in solar energy and explore the future of this Administration's effort to refocus funding on early-stage research and innovative technology.

This September, the Department of Energy's Office of Energy Efficiency and Renewable Energy, or EERE, announced that the cost of utility-scale solar power has met the SunShot 2020 goal of under 6 cents per kilowatt-hour.

This is an incredible achievement by solar power companies across the country, including many in my home state of Texas. More importantly, with this new benchmark, EERE announced a new direction in solar energy research, prioritizing early-stage research and emerging solar energy technology instead of cost reductions for commercially available technology.

This new research will focus on two primary areas. The first is innovative technology in Concentrating Solar Power, or CSP, systems which use mirrors to reflect and concentrate sunlight onto a focused point in order to heat water and create steam to power turbines and create electricity.

The second research priority relates to power electronics technologies. This technology connects solar photovoltaic, PV, arrays to the electrical grid. Advancements in power electronics will help grid operators and consumers to manage electricity use.

EERE also recently released the fiscal year 2018–2022 multi-year program early-stage research for PV technology, for grid integration, PV materials, and for concentrating solar thermal power.

EERE will focus on advancements in fundamental technologies and research in materials science that will drive solar energy innovation forward. For example, at the National Renewable Energy Laboratory, NREL, materials science research is advancing the capabilities of solar energy technology.

As you will hear from NREL Lab Director, Dr. Martin Keller, linking basic and early-stage research in materials to applied solar energy research can produce major breakthroughs in this area of technology. One example is the lab's experiments with perovskite solar cell technology which uses a low-cost and high-efficiency material that has widespread application prospects. Perovskites may provide a low-cost and scalable material for solar cells or semiconductors and could lead to more efficient solar technology.

Perovskite solar cells have the potential for a "roll on" application, similar to printing newspapers, and research in materials science at NREL could provide a fundamentally new way for industry to actually manufacture solar cells. These research breakthroughs can transform energy markets far more than using limited research dollars to push deployment of today's existing solar technology.

Congress should focus on making America the global leader in research and innovation in the energy sector. We do not need to pick winners and losers in energy markets to support next-generation technology.

I want to thank our accomplished panel of witnesses for testifying today and I look forward to a productive discussion about the future of solar energy research.

[The prepared statement of Chairman Weber follows:]

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

For Immediate Release
December 13, 2017

Media Contacts: Thea McDonald, Brandon VerVelde
(202) 225-6371

Statement from Randy Weber (R-Texas)

Advancing Solar Energy Technology: Research Trumps Deployment

Chairman Weber: Welcome to today's Energy Subcommittee hearing. Today, we will examine the status of U.S. research in solar energy and explore the future of this administration's effort to refocus funding on early-stage research and innovative technology.

This September, the Department of Energy's Office of Energy Efficiency and Renewable Energy, or EERE, announced that the cost of utility-scale solar power has met the SunShot 2020 goal of under six cents per kilowatt-hour.

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One example is the lab's experiments with perovskite solar cell technology, which uses a low-cost and high-efficiency material that has widespread application prospects. Perovskites may provide a low cost and scalable material for solar cells or semiconductors, and could lead to much more efficient solar technology.

Perovskite solar cells have the potential for a "roll on" application, similar to printing newspapers, and research in materials science at NREL could provide a fundamentally new way for industry to manufacture solar cells. These research breakthroughs can transform energy markets far more than using limited research dollars to push deployment of today's solar technology.

Congress should focus on making America the global leader in research and innovation in the energy sector. We don't need to pick winners and losers in energy markets to support next generation technology.

I want to thank our accomplished panel of witnesses for testifying today and I look forward to a productive discussion about the future of solar energy research.

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Chairman WEBER. And with that, I recognize Ranking Member, Ms. Rosen.

Ms. ROSEN. Thank you. Good afternoon and thank you, Chairman Weber, for holding this important and timely hearing today. You know, it's been more than five years since this Committee last held a hearing specifically on solar energy. With the expanding deployment of solar power across our nation, the incredible advances made in this area over the past five years, I'm very glad we're getting a chance to reexamine these technologies.

I'd also like to thank this distinguished panel of witnesses for being here. I'm very interested in what all of you have to say that will help us further enable the development of this critical resource and this critical industry.

Solar energy is an important and growing portion of our nation's energy consumption. Its success is not only because it is a clean and renewable energy source, but also because it has become cost-competitive with other types of energy. In my State of Nevada we are currently getting about nine percent of our energy needs from solar technology and have doubled the amount of megawatts installed in the past year. In fact, a year ago the City of Las Vegas fulfilled its promise to run all of its municipal facilities with 100 percent renewable energy.

On a personal level, I know firsthand from my life before Congress, the enormous benefits of solar energy. As the former president of Nevada's largest synagogue, I helped facilitate the installation of one of the largest solar projects by a nonprofit in Henderson, Nevada, cutting our energy costs by nearly 70 percent.

I'm optimistic that the growth of solar will continue because of the research being carried out at our national labs, universities, and in American solar companies. For more than a decade, the University of Nevada Las Vegas has engaged in extensive research on renewable energy, and recently its Solar Decathlon team took first place for innovation and second place for both engineering and architecture in the national DOE competition. UNLV is also leading an initiative to establish a Solar Solutions Center, designed to employ research, policy analysis, and the business community to create solar energy jobs and improve technology. Strong investments in R&D will be vital to decreasing the cost of solar energy.

However, I'm concerned about the consistent attacks on solar energy from both the current Administration and the Republican-led Congress. The Administration's proposed cuts of over 2/3 to the DOE's solar technology program budget will have a profound and negative impact on our nation's ability to utilize this resource for the benefit of our environment and our economy. Solar energy is less expensive now than it ever has been, and it can continue to become more affordable, saving our constituents and small businesses money.

In addition, I am deeply concerned by the Republican tax bill that, among other incredibly harmful provisions, will hurt our solar industry by eliminating the ten percent investment tax credit for large-scale solar projects. I submitted an amendment to prevent the eventual elimination of tax credits for solar and geothermal energy, which unfortunately the majority refused to adopt.

While this Administration and my Republican colleagues are trying to justify reducing U.S. investments in solar, China is spending more than double the United States on renewables with initiatives to continue spending through 2030 at levels that far outstrip the United States. Without strong support and investment by the federal government, we are likely to lose jobs in this growing industry and the opportunity to control our own energy future.

My State of Nevada currently has over 8,000 solar jobs, and the projected solar growth is over 20 percent. We should be continuing to invest in the solar energy sector to create more jobs, not gutting proven programs that work.

The next breakthroughs in solar energy are coming, whether here in the U.S. or somewhere else. The only question is whether the U.S. will lead the way or whether we will pay foreign companies for our energy needs and lose jobs overseas.

I am looking forward to what the witnesses have to say about how we keep these jobs in our country and achieve the clean energy future that our citizens deserve. Thank you.

[The prepared statement of Ms. Rosen follows:]

OPENING STATEMENT
Representative Jacky Rosen (D-NV)

House Committee on Science, Space, and Technology
Subcommittee on Energy
Advancing Solar Energy Technology: Research Trumps Deployment
December 13, 2017

Good afternoon and thank you, Chairman Weber, for holding this important and timely hearing today. It has been more than five years since this Committee last held a hearing specifically on solar energy. With the expanding deployment of solar power across our nation and the incredible advances made in this area over these past five years, I'm very glad we're getting a chance to reexamine these technologies. I would also like to thank this distinguished panel of witnesses for being here. I'm very interested in what all of you have to say that will help us further enable the development of this critical resource and industry.

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I'm optimistic that the growth of solar will continue because of the research being carried out at our national labs, universities, and in American solar energy companies. For more than a decade, the University of Nevada Las Vegas (UNLV) has engaged in extensive research on renewable energy, and recently its Solar Decathlon team took first place for Innovation and second place for both Engineering and Architecture in the national DOE competition. UNLV is also leading an initiative to establish a "Solar Solutions Center", designed to employ research, policy analysis, and the business community to create solar energy jobs and improve technology. Strong investments in R&D will be vital to further decreasing the cost of solar energy.

However, I am very concerned by the consistent attacks on solar energy from both the current Administration and the Republican-led Congress. The Administration's proposed cut of nearly two thirds to DOE's solar technology program budget will have a profound and negative impact on our nation's ability to utilize this resource for the benefit of our environment and economy. Solar energy is less expensive now than it has ever been and it can continue to become more affordable, saving our constituents and small businesses money.

In addition, I am deeply concerned by the Republican tax bill that, among other incredibly harmful provisions, will hurt our solar industry by eliminating the 10 percent investment tax credit for large-scale solar projects. I submitted an amendment to prevent the eventual elimination of tax credits for solar and geothermal energy, which unfortunately the Majority refused to adopt.

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The next breakthroughs in solar energy are coming, whether here in the U.S. or somewhere else in the world. The only question is whether the U.S. will lead the way or whether we will pay foreign companies for our energy needs and lose jobs overseas.

I am looking forward to hearing what the witnesses have to say about how we keep these jobs in our country and achieve the clean energy future that our citizens deserve. Thank you.

Chairman WEBER. Thank you, Ms. Rosen. I now recognize the Chairman of the Full Committee, Mr. Smith.

Chairman SMITH. Thank you, Mr. Chairman. Today, the Subcommittee on Energy will examine the Department of Energy's efforts to refocus the solar energy program on early-stage research and breakthrough solar technologies.

This hearing specifically will consider the rapid integration of solar energy technology in the energy market and discuss the appropriate role of DOE investment in solar energy research in the future. Fundamental science and technological capabilities still challenge solar energy advancement, but it is crucial that the Department focus on basic and early-stage research that cannot be conducted by the private sector.

For too long, the American public saw their taxpayer funds pick winners and losers in the energy market. The previous Administration often played favorites and invested heavily in the deployment of photovoltaic technology into energy markets. While this approach may have sped the deployment of today's solar energy, it did not lead to the kind of breakthrough technology in solar energy, manufacturing, and energy storage that is needed to help solar energy compete without tax credits, mandates, or subsidies.

This committee supports DOE's role in funding basic and early-stage research that the private sector is truly unable to explore on its own.

It is these kinds of breakthroughs, in new materials, electrochemistry, and advanced manufacturing that will lead to the next generation of solar energy technology.

The President's fiscal year 2018 budget request also supports investment in early-stage applied research in solar energy. The budget request directs federal investment into the kind of research that industry cannot support and that can lead to new solar energy technology. This clearly signals the Administration's push for American energy dominance and independence.

I want to welcome Mr. Daniel Simmons, the Principal Deputy Assistant Secretary for EERE to testify today. It is critical that we hear directly from the department of policy changes and the direction of DOE research programs.

I thank our witnesses today for testifying about their valuable efforts in renewable energy programs, research, and for sharing their insights into emerging solar energy technology. I look forward to a productive discussion about early-stage research at DOE and the right approach to federal research investment. Thank you, Mr. Chairman. I yield back.

[The prepared statement of Chairman Smith follows:]

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

For Immediate Release
December 13, 2017

Media Contacts: Thea McDonald, Brandon VerVelde
(202) 225-6371

Statement from Lamar Smith (R-Texas)

Advancing Solar Energy Technology: Research Trumps Deployment

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I thank our witnesses today for testifying about their valuable efforts in renewable energy programs, research and for sharing their insights into emerging solar energy technology. I look forward to a productive discussion about early-stage research at DOE and the right approach to federal research investment.

###

Chairman WEBER. Thank you, Mr. Smith. I now recognize the Ranking Member of the Full Committee for a statement. Ms. Johnson?

Ms. JOHNSON. Thank you very much, Mr. Chairman, and I appreciate you holding this hearing. It has been several years since this Committee has held a hearing that closely examined solar energy research and development activities carried out by the Department of Energy. These years have been a very consequential time for this sector. We have seen the price of solar energy decrease dramatically, and solar deployment continues to grow here in the U.S. and around the world.

The Solar Energy Technologies Office within DOE's Office of Energy Efficiency and Renewable Energy has stewarded key research that has resulted in important innovations in the diverse commercial market for solar energy. Moreover, due in large part to investments enabled by the Loan Programs Office of DOE, the United States now has a vibrant and growing utility-scale solar industry.

In that regard, I would like to congratulate the scientists and researchers at the Department of Energy, the national laboratories, and their private sector partners that helped us achieve a key milestone in the SunShot Initiative. Just this past September, DOE announced that the program achieved the cost reduction goals for utility-scale solar three years early. These smart government investments have resulted in significant private sector investment here in the U.S., which has led to a vibrant solar industry and well-paying jobs for Americans across the country.

Unfortunately, this Administration and some of my colleagues in Congress do not recognize the realities of this industry. If we do not invest, others will. In fact, our international competitors have been investing and will continue to prioritize solar technology development. China is clearly beating us at our own game. Meanwhile we are quibbling about whether the federal government should invest in late-stage research or just early-stage activities, whatever that means, instead of supporting robust R&D investments across the innovation spectrum that will make the U.S. more competitive.

The Trump Administration's budget proposed major cuts in solar energy R&D, including a 66 percent cut from prior year funding for the Solar Energy Technologies Office within EERE. It also called for an outright elimination of the Loan Programs Office, which enabled the commercialization of several first-of-a-kind, large-scale solar power projects.

Now, I am not going to tell you that every program the department currently implements is perfect. That wouldn't be research. I wouldn't tell you that reforms should not be considered or that reasonable people cannot simply disagree on the best way to allocate its resources, even after a careful, rigorous review. One of my primary concerns now is that such a thoughtful review never actually took place before proposing these draconian cuts. In fact, Administration officials confirmed after they released the budget that there was no engagement with the private sector to determine what industry would be able or willing to fund in the absence of federal investment. That is simply unacceptable.

Defunding solar energy at DOE may be a nice political talking point for some, but when it comes to U.S. competitiveness and our economic growth, such a proposal is ill-advised and shortsighted. I am hoping we can have a productive dialogue today that will better inform us about the realities of this industry both here and around the world. We need to know what we have to lose before we are slashing the R&D budgets that are the livelihood and likelihood of any future economy.

Thank you again, Mr. Chairman, for having the hearing, and I yield back.

[The prepared statement of Ms. Johnson follows:]

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

House Committee on Science, Space, and Technology
Energy Subcommittee Hearing
Advancing Solar Energy Technology: Research Trumps Deployment
December 13, 2017

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Thank you again, Mr. Chairman. I yield back.

Chairman WEBER. I thank the gentlelady from Texas. Today our first witness is Mr. Daniel Simmons, Principal Deputy Assistant Secretary, Office of Energy Efficiency and Renewable Energy at the Department of Energy. Previously, Mr. Simmons served as the Institute for Energy Research's Vice President for Policy, Director of the National Resources Task Force at the American Legislative Exchange Council, and was a research fellow at the Mercatus Center. Mr. Simmons received his bachelor's degree from Utah State University and his law degree from George Mason University School of Law. Welcome, Mr. Simmons.

Our second witness today is Dr. Martin Keller, Director of the National Renewable Energy Laboratory. Previously Dr. Keller served as the Associate Laboratory Director for Energy and Environmental Sciences at Oak Ridge National Laboratory. He received his doctorate in microbiology from the University of Regensburg in Germany. Welcome to you.

Our third witness is Dr. Steve Eglash? Okay. Executive Director of Strategic Research Initiatives in the Computer Science Department at Stanford University. Previously, Dr. Eglash was President and CEO of the solar energy company Cyrium Technologies as well as a consultant for the National Renewable Energy Laboratory and the U.S. Department of Energy. Dr. Eglash received his Ph.D. and MS from Stanford University and his bachelor's degree from the University of California at Berkeley, all in electrical engineering. Welcome, Dr. Eglash.

Our last witness today is Mr. Kenny Stein, Director of Policy at the Institute for Energy Research. Previously, Mr. Stein worked in policy roles at FreedomWorks and the American Legislative Exchange Council. He received his law degree from the University of Houston. You're a cougar. Me, too. Good for you. Let the record show that Mr. Stein's testimony will carry a double in credence here today. He received his law degree from the University of Houston and his bachelor's degree from American University. Welcome, Mr. Stein.

I now recognize Mr. Simmons for five minutes to present his testimony. Be sure your mic is on, please.

TESTIMONY OF MR. DANIEL SIMMONS, PRINCIPAL DEPUTY ASSISTANT SECRETARY, OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY, US DEPARTMENT OF ENERGY

Mr. SIMMONS. Good afternoon Chairman Smith, Chairman Weber, Ranking Member Johnson, Veasey, and Ms. Rosen and Members of the Committee. Thank you for inviting the Department of Energy to testify. My name is Daniel Simmons, and I am the Principal Deputy Assistant Secretary for Energy Efficiency and Renewable Energy at the Department of Energy.

Solar energy technologies are an important source of energy for our nation, and I thank you for the opportunity to discuss our research to advance these technologies.

Ten years ago, the solar market looked very different than it does today. There were only 1.1 gigawatts installed in the United States, representing less than 0.01 percent of the nation's energy mix. Now, there are more than 50 gigawatts installed, providing nearly one percent of U.S. electricity and growing rapidly. Over 80 percent of the solar ever installed was installed in the last five years, and in the next five years it is projected to triple.

Over the past ten years, solar costs have declined dramatically. For example, earlier this year, as Chairman Weber noted, the Solar Energy Technology Office announced that the industry met the SunShot utility-scale cost goal of 6 cents per kilowatt hour three years early.

While there are many reasons for solar prices to have declined and installations to have risen, federal research and development plays a role. This Administration is committed to developing a wide range of energy resources through R&D and believes that federal funding should prioritize basic and early-stage applied research. As stated in the joint Office of Management and Budget and the Office of Science and Technology policy memo on R&D priority areas for the fiscal year 2019 budget formulation, "American leadership in science and technology is critical to achieving this Administration's higher priorities: national security, economic growth, and job creation. American ingenuity combined with free-market capitalism have driven and will continue to drive tremendous technological breakthroughs.

Development of domestic energy sources should be the basis for a clean energy portfolio composed of fossil, nuclear, and renewable energy sources. Agencies should invest in early-stage, innovative technologies that show promise in harnessing American energy resources safely and efficiently. As proposed in the President's fiscal year 2018 budget, federally-funded energy R&D should continue to reflect an increased reliance on the private sector to fund later-stage research development and commercialization of energy technologies."

DOE's Solar Energy Technologies Office focuses primarily on reducing the cost of various solar technologies, including photovoltaic and concentrating solar thermal power.

The dramatic cost reductions in solar technology provide an opportunity for the Administration to re-focus the solar office's research on a longer-term challenge, grid integration. In the long term, the primary challenge facing solar is not necessarily cost but reliability and integration of solar power into the grid. While lower prices have helped drive new capacity installations, more work is needed to make solar a reliable, on-demand energy resource.

This year, DOE has approved over $100 million in financial assistance to advance our early-stage research priorities around solar reliability and grid integration. Examples include up to $62 million to support advances in concentrated solar power technologies. Up to 20 million is dedicated to early-stage projects to advance power electronics technologies. That is the interface between the grid and solar panels. And up to 10 million to support improved solar forecasting.

Each of these research areas will help make it easier to integrate solar energy into the electric grid. In addition to this work, EERE works with the Office of Electricity Delivery and Energy Reliability through DOE's Grid Modernization Initiative. One important focus is researching solar plus storage. Energy storage allows variable sources of energy, such as solar, to be used when it's needed the most. Making solar power available when energy is needed is the most critical challenge for the solar industry today. DOE's solar R&D is focused on these critical energy challenges of grid reliability, resilience, and integration. EERE will continue to focus on early-stage research and development to advance solar technologies, while forging strong partnerships with the private sector to maximize the impact of federal funding.

Thank you for the opportunity to testify today, and I look forward to answering your questions.

[The prepared statement of Mr. Simmons follows:]

Testimony of Principal Deputy Assistant Secretary Daniel R Simmons

Office of Energy Efficiency and Renewable Energy

U.S. Department of Energy

Before the

Committee on Science, Space, and Technology

Subcommittee on Energy

United States House of Representatives

December 13, 2017

Good afternoon Chairman Weber, Ranking Member Veasey, and members of the Committee. Thank you for inviting the Department of Energy to testify. My name is Daniel Simmons, and I am the Principal Deputy Assistant Secretary for Energy Efficiency and Renewable Energy (EERE) at the U.S. Department of Energy. Solar energy technologies are an important source of electricity for our nation and I thank you for the opportunity to discuss our research to advance solar technologies.

Industry overview

Ten years ago, the solar market looked very different. There were only 1.1 gigawatts installed in the United States, representing less than 0.01% of the nation's energy mix. Now, there are nearly 50 gigawatts[1] installed, providing nearly 2% of U.S. electricity in the first nine months of 2017,[2] and growing quickly. Over 80% of solar ever installed was installed *in the last five years*, and in the next five years, it is projected to *triple*.[3]

In the first half of 2017, 25% of all new electricity capacity installed came from solar[4] and those systems are being deployed all across the United States. While California leads the country in solar installations, 14% of all domestic installations in the first 9 months of 2017 were located in Texas and another 13% in North Carolina.[5]

Over the past ten years, solar costs have declined dramatically. Earlier this year, the Solar Energy Technology Office announced that the industry met the utility-scale cost goal of 6 cents per kilowatt hour three years early. That's measured without including incentives and with an average amount of sunshine.[6] Globally, in sunny locations, such as Arizona and Mexico, we are already seeing solar installations being delivered at even lower cost.

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[1] Capacity total converted to DC using EIA, Electric Power Monthly.
[2] Measured in the first nine months of 2017. EIA, Electric Power Monthly, Table 1.17.b
[3] SEIA/GTM, Solar Market Insight Report
[4] 2016: EIA, "Electric Power Monthly" Table 6.1; 2017 (solar): EIA, "Electric Power Monthly" Table 6.1A; 2017 (remainder): FERC, "Energy Infrastructure Update."
[5] 2016: EIA, "Electric Power Monthly" Table 6.2b; August/Feb 2017
[6] Kansas City was used as an average sunlight measure for this goal.

The importance of early stage research and development

While there are many reasons why solar prices have declined and installations have risen, federal research and development (R&D) certainly plays a role. This Administration is committed to developing a wide range of energy resources through R&D, and believes that federal funding should prioritize basic and early-stage applied research. As stated in the joint Office of Management and Budget and Office of Science and Technology policy memorandum to the heads of executive departments and agencies, M-17-30, the following are R&D priority areas for FY 2019 Budget formulation:[7]

> American Prosperity
> American leadership in science and technology is critical to achieving this Administration's higher priorities: national security, economic growth, and job creation. American ingenuity combined with free-market capitalism have driven, and will continue to drive, tremendous technological breakthroughs. American inventions have fundamentally changed the course of human history: the incandescent light bulb, the airplane, satellite navigation, and the internet have improved the lives of millions of Americans and billions around the world. In spurring future advances, Federal funding of research and development (R&D) programs and research infrastructure can play a crucial role.
>
> American Energy Dominance
> A consistent, long-term supply of lower-cost American energy will provide security through energy independence and help create a stable supply of high-paying jobs, while lower prices for electricity and fuel will spur American prosperity. Development of domestic energy sources should be the basis for a clean energy portfolio composed of fossil, nuclear, and renewable energy sources. Agencies should invest in early-stage, innovative technologies that show promise in harnessing American energy resources safely and efficiently. As proposed in the President's FY 2018 budget, federally-funded energy R&D should continue to reflect an increased reliance on the private sector to fund later-stage research development, and commercialization energy technologies.
>
> Supporting Innovative Early-Stage Research
> Basic and early-stage applied research are critical components of the American research enterprise and the basis of new technological development and commercialization. However, in the development of high-payoff technology, early-stage research often involves greater uncertainty and may not provide the economic incentive needed to attract private sector investment. Therefore, agencies should give priority to funding basic and early-stage applied research that, supplemented by private sector financing of later-stage R&D, can result in the development of transformative commercial products and services. Strong partnerships with the private sector will be critical to maximizing the efficacy of Federal funding. Furthermore, agencies should take advantage of innovation from the private sector, where possible, to adapt to Federal needs, rather than re-inventing solutions in parallel.

Expanded mission for solar R&D

EERE is dedicated to making energy more affordable and reliable through early-stage applied research in three broad areas: energy efficiency, renewable power, and sustainable transportation. Within the

[7] https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/memoranda/2017/m-17-30.pdf

renewable power area, EERE's Solar Energy Technologies Office (SETO) focuses primarily on reducing the cost of various solar technologies, including photovoltaic and concentrating solar thermal power.

The dramatic cost reductions in solar technology provide an opportunity for the Administration to re-focus SETO's research on a longer-term challenge: grid integration. In the long term, the primary challenge facing solar is not cost, but reliability. While lower prices have helped drive new capacity installations, more work is needed to make solar a reliable, on-demand energy resource.

Solar has dramatically grown over the past decade, but adding large amounts of solar to the grid presents grid reliability challenges. To explain these challenges, it is important to note how electricity is used throughout the day. Consumers use the least amount of electricity at night, when they are asleep. Demand starts rising as people wake and generally peaks in the afternoon and early evening before tapering off. Utilities balance this relatively predictable demand profile by ramping up and ramping down power plants to balance supply with demand.

Photovoltaic solar helps meet demand when the sun is up, but obviously when the sun sets, production stops. This means that on-demand sources of electricity generation are required to ramp up quickly to meet early evening demand. While mainstream awareness of these challenges is emerging, SETO is refocusing its efforts on utility demand and grid forecasting strategies.

This year, DOE has approved over $100 million in financial assistance to advance our new early-stage research priorities around solar reliability. Examples include:

- **Concentrated Solar Power (CSP):** Up to $62 million will support advances in CSP technologies to enable on-demand solar energy. CSP technologies use mirrors to reflect and concentrate sunlight onto a focused point where it is collected and converted into heat. This thermal energy can be stored and used to produce electricity when the sun is not shining or integrated into other applications, such as producing fresh water or supplying process heat.[8]
- **Power Electronics:** Up to $20 million is dedicated to early-stage projects to advance power electronics technologies. Such innovations are fundamental to solar PV as the critical link between PV arrays and the electric grid. Advances in power electronics will help grid operators rapidly detect problems and respond, protect against physical and cyber vulnerabilities, and enable consumers to manage electricity use.[9]
- **Solar Forecasting:** The Solar Forecasting 2 funding program builds on the Improving Solar Forecasting Accuracy funding program to support projects that generate tools and knowledge to better predict solar power generation. These projects will improve the ability to manage the variability of solar power, and will enable more reliable and cost-effective integration of solar power onto the grid. This funding program supports the Energy Department's broader Grid Modernization Initiative, a crosscutting effort that helps to better integrate all sources of electricity, improve the security of our nation's grid, solve challenges of energy storage and

[8] Energy Department, "Energy Department Announces Achievement of SunShot Goal, New Focus for Solar Energy Office," September 12, 2017.
[9] Energy Department, "Energy Department Announces Achievement of SunShot Goal, New Focus for Solar Energy Office," September 12, 2017.

distributed generation, and provide a critical platform for U.S. competitiveness and innovation in a global energy economy.[10]

Each of these research areas will help make it easier to integrate solar energy into the electric grid. In addition to this work, EERE works with the Office of Electricity Delivery and Energy Reliability (OE) through DOE's Grid Modernization Initiative. For example, researchers at Lawrence Livermore National Lab, funded by EERE and OE through the Grid Modernization Laboratory Consortium, are researching PV plus storage. Energy storage allows variable sources of energy, such as solar, to be used when it's needed.

This DOE-funded research aims to show that distributed solar PV and storage can help communities recover quickly from a major disaster like an earthquake, hurricane or flood. Currently, once electricity is lost, restarting the grid is performed manually using special generators. It's an extremely slow process that does not account for electricity that could be generated by distributed sources. Using "agile islanding"—forming microgrids around local solar customers—solar electricity can help to restart local power supplies and jumpstart critical grid functions. This project is one of seven Resilient Distribution Systems projects announced earlier[11] this year with up to $32 million in early-stage R&D funding for DOE national laboratories.

While DOE is focusing its solar R&D on reliability issues, the Department will continue work to reduce costs. Photovoltaic technologies have made major advances in recent years, but there is still potential to improve photovoltaic performance and lower cost. A typical commercial photovoltaic system that you would install on your roof converts about 16% of the light that strikes it into electricity. Increasing the amount of energy generated by that same system is a win-win—you get more energy without having to install more solar panels.

One innovation being developed by the National Renewable Energy Laboratory uses different materials within a single solar cell that are tailored to capture more of the light spectrum. These researchers designed and fabricated a four junction solar cell that set a world record of 45.7% conversion efficiency, and they are now aiming to continue their world leadership and hit 50% efficiency.

What the Future Holds

Making solar available when energy is needed is the most critical challenge for the solar industry. The new foundation for DOE's solar R&D is on these critical energy challenges of grid reliability, resilience, and integration. EERE will continue to focus on early-stage research and development to advance solar technologies, while forging strong partnerships with the private sector to maximize the impact of federal funding.

Thank you for the opportunity to testify today, and I look forward to answering your questions.

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[10] Energy Department, "Energy Department Announces More than 90% Achievement of 2020 SunShot Goal, Sets Sights on 2030 Affordability Targets," November 14, 2016.

[11] Energy Department, "Energy Department Invests Up to $50 Million to Improve the Resilience and Security of the Nation's Critical Energy Infrastructure," September 12, 2017.

Bio of Principal Deputy Assistant Secretary Daniel R Simmons

In his role as Principal Deputy Assistant Secretary in the Office of Energy Efficiency and Renewable Energy (EERE), Daniel Simmons leads EERE to achieve its vision of a strong and prosperous America powered by clean, affordable, and secure energy. He oversees technology development in the energy efficiency, renewable power and sustainable transportation sectors.

Daniel served as the Institute for Energy Research's Vice President for Policy, overseeing its energy and environmental policy work at the state and federal level.

He previously served as director of the Natural Resources Task Force at the American Legislative Exchange Council, was a research fellow at the Mercatus Center, and worked as professional staff on the Committee on Resources of the U.S. House of Representatives.

He is a graduate of Utah State University and George Mason University School of Law.

Chairman WEBER. Thank you, Mr. Simmons. You ended right on zero. Dr. Keller, you're recognized for five minutes.

TESTIMONY OF DR. MARTIN KELLER, DIRECTOR, NATIONAL RENEWABLE ENERGY LABORATORY

Dr. KELLER. Chairman Weber, Chairman Smith, Ranking Member Veasey, Rosen, Johnson, and our own Congressman Perlmutter, Members of the Subcommittee, thank you for this opportunity to address the future research opportunities for solar energy and the many benefits that advanced solar technologies can deliver for our nation.

I'm Martin Keller. I'm the Director of the U.S. Department of Energy's National Renewable Energy Laboratory, or commonly called NREL, based in Golden, Colorado. My career has included research positions in the private sector and more than a decade within the national lab complex. I previously was an Associate Lab Director at Oak Ridge National Laboratory and before that led the technology development for a San Diego-based start-up company. I hold a doctorate in microbiology from the University of Regensburg in Germany. And my entire career has been about integrating foundational science into important new applications.

In my view, the subject of today's hearing could not be more timely nor more important to the energy future of our country. Although solar energy accounts for about 1.8 percent of U.S. electrical generation today, it is on a remarkable trajectory of growth. Last year, solar was the nation's leading source of new electric generation capacity. It's also an economic force. More than 260,000 Americans are employed in the solar industry with 51,000 jobs added just in 2016. This marked the fourth consecutive year of more than 20 percent growth.

Our research has made incredible progress on bringing solar technologies into the mainstream. And solar is in fact becoming competitive with conventional power from the grid. This said, we cannot afford to slow our progress on innovating solar technology.

To achieve solar potential, an ongoing program of federally supported early-stage research is needed. NREL and other national labs have the greatest expertise and the unique facilities to lead this effort.

I would like to share with you examples of how early-stage research can deliver potential game-changing breakthroughs in solar research. Fundamental material research in the solar area expanded into a new class of PV materials called perovskites. These materials hold a great promise to increase efficiency by cutting costs. One of the benefits of these materials is the potential of extremely high-speed manufacturing. Just imagine solar cells being produced at the rate of speed that a newspaper is produced on a commercial printing press. What is now needed is a federally supported hub for perovskite research, coordinating the work of industry, universities and national labs to deliver breakthroughs needed to swiftly bring this technology to the market.

Other examples are further development of lightweight PV materials and new production methods for very high efficient layered solar cells. Lightweight PV materials are becoming increasingly important to the U.S. military to power the computers and communication systems of our soldiers on the ground. Very high-efficient solar cells manufactured through much cheaper processes may eventually give our military—the commanding power of perpetual flight. We're optimistic that the several research efforts I just outlined could bring about a revolution in PV technology and inject new vitality into U.S.-based solar manufacturing.

Even with advances in grid integration technology, we will certainly need storage technologies. Because of this, storage for solar energy warrants complimentary research dedicated to its own unique requirements. As distributed solar generation becomes a larger part of the generation mix, our electric grid systems have the potential to become even stronger, with greater flexibility and resilience. Energy integration at this complex level presents a deep scientific challenge. This research path is crucial not only for solar but for the entire U.S. electric grid.

As solar power becomes more prevalent in the United States, we will be able to use surplus solar power to enhance economic competitiveness. The potential is to convert solar electricity or heat into viable products like fuels, hydrogen, or other chemicals. It can provide an economic advantage to U.S. industry through a sustained scientific research effort along these multiple pathways.

In addition to solar photovoltaic technologies, concentrating solar power, or CSP, has significant potential as well. Here, we need to develop systems that run at higher temperatures and boost operating efficiency. And since CSP can use thermal energy to expand the period in which it produces power, CSP could give grid operators considerable flexibility from providing base load to peaking generation.

As we contemplate the research portfolio for the years ahead, we should remember that other nations are currently ramping up their own government-supported solar research. If we fail to maintain our innovation leadership in solar, others will be happy to take our place.

In conclusion, I am not exaggerating when I say that researchers at my laboratory and around the country are excited and eager to tackle these challenges and bring us the important advancements in solar technology that we need for our nation's energy future.

[The prepared statement of Dr. Keller follows:]

Prepared Statement of Dr. Martin Keller
Director
National Renewable Energy Laboratory
For the House Science, Space & Technology Committee
Subcommittee on Energy

December 13, 2017

Chairman Weber, Ranking Member Veasey, members of the Subcommittee, thank you for this opportunity to address the future research opportunities for solar energy, and the many benefits that advanced solar technologies can deliver for our nation.

My name is Martin Keller, and I'm the Director of the U.S. Department of Energy's National Renewable Energy Laboratory, or NREL, in Golden, Colorado. My career has included research positions in the private sector and more than a decade within the National Lab complex. Before coming to NREL in 2015, I was the Associate Lab Director, and led the DOE BioEnergy Science Center, at Oak Ridge National Laboratory in Tennessee. I previously conducted technology development for a San Diego-based start-up company, and I hold a Doctorate degree in Microbiology from the University of Regensburg in Germany. My entire career has been about integrating foundational science into important new applications. This experience has given me a deep understanding of and profound appreciation for the role that federally supported scientific research can play in maintaining our nation's leadership in science and innovation—and also, how those accomplishments can drive U.S. competitiveness.

In my view, the subject of today's hearing could not be more timely, nor more important to the energy future of our country. For although solar energy accounts for 1.8 percent of U.S. electrical generation today, it is on a remarkable trajectory of growth, with tremendous longer-term potential. Total installed photovoltaic capacity surpassed 40 gigawatts in 2016—a record year—nearly double the rate of growth seen in 2015. For the first time, solar ranked as the nation's leading source of new electric generating capacity on an annual basis, with 39 percent of all *new* electricity generation capacity in the country coming from solar. And the benefits are increasingly seen nationwide: some 22 states each added more than 100 megawatts last year.

This also means that solar energy is becoming a significant economic force. The Solar Foundation reports that more than 260,000 Americans are employed in the solar industry, with 51,000 jobs added in 2016. This marked the fourth consecutive year of more than 20 percent growth, and the number of solar jobs has nearly tripled since 2010.

Since I arrived at NREL, one of the most exciting aspects of our work has been in the field of solar energy. In the four decades of work we've done at NREL, we have made incredible progress on bringing solar technologies into the mainstream. And because of this work, we are at the point where solar is becoming competitive with conventional power from the grid in many parts of the country. But just as innovation for the automobile didn't stop when that technology reached parity with the horse, we cannot afford to slow our progress on innovating solar technology just because we are reaching parity with the grid.

To give you an idea of how far we've come: The first photovoltaic, or PV, cell produced electricity equal to 4 percent of the energy it absorbed from the sun—what we refer to as 4 percent conversion efficiency. The solar cells based on that technology cost about $300 a watt. Today, costs have plummeted. The price of commercially available modules is tipping toward 30 cents a watt, and record research cells based on advanced technologies are approaching 50 percent efficiency.

Despite this remarkable progress, there is still much more that remains to be done. Solar technology has great unmet potential. But to reach that potential, foundational scientific R&D and the breakthroughs it can produce are needed to accomplish the goals for a competitive U.S. market, 50-year product lifetimes, wholesale power prices (i.e., 3 cents/kWh), positive grid impact, and power anywhere the sun shines.

Transformative Solar Science

Energy provides the foundation for our economy. As such, it is imperative that the United States continue to be an innovative leader in advanced energy, including PV technology. Investments in research over recent decades have enabled U.S. industries to establish leadership positions. Examples include First Solar (leading in cadmium telluride, CdTe, modules), SunPower (leading in high-efficiency silicon modules), DuPont (leading in materials that are critical components of PV cells), and 1366 (providing conventional silicon-wafer alternatives). Continued early-stage research will provide the foundation for the next generations of solar technologies, creating new business opportunities and jobs, and sustaining our leadership role in global solar innovation.

Fundamental science underpins every aspect of what we do in photovoltaics. This is not just true for the cell materials, but also for the necessary power electronics, energy storage, and grid integration of solar energy. This science ranges from new materials discovery for solar absorbers, to new and low-cost manufacturing technologies, new contact materials, tandem junctions, module encapsulation materials, high-bandgap semiconductors, and new rapidly charging battery materials.

It even extends to newly developed intelligent and autonomous control algorithms that operate at every level in the energy system, from module to grid, in a cyber-secure manner. These autonomous control algorithms allow a solar power system to coordinate seamlessly with utilities and grid operators, to meet the nation's needs for reliable and dispatchable energy.

Fundamental science—in the fields of materials science, chemistry and electrochemistry, semiconductor physics, and computational sciences—is enabling revolutionary advances that lead not just to grid-scale reliable energy, but also to new applications. Lightweight PV materials are becoming increasingly important to the U.S. military, which is seeking advanced PV for powering vital computers and communication systems for soldiers on the ground, and a host of other mobile applications. Lightweight and high-efficiency PV may additionally give drones the commanding power of perpetual flight. NREL currently has several solar R&D projects for the Pentagon that delve deeply into the science behind new manufacturing processes, for established materials like gallium arsenide (GaAs), and CdTe, that could further drive down costs and give U.S. industry a competitive advantage.

NREL, together with other labs, academic institutions, and industry partners, is pushing forward with science and engineering in each of these areas. For instance, NREL has teamed with the Stanford Linear Accelerator, or SLAC, on fundamental computational materials discovery by design, to explore new synthetic approaches and to integrate these materials in new solar concepts. Materials discovery remains a consequential force for innovation, beginning with the solar absorbers that produce electricity, to the interfacial materials that make up a cell, to module materials, and all the way to the power electronics and power-system components that connect modules to the grid.

Driving Current Technologies to the Next Stage

Some decades ago, NREL developed the multijunction solar cells that are now deployed on satellites and the Mars rover. These cells are currently much too expensive to employ in terrestrial applications, but NREL is working to bring this technology back to Earth. By employing novel deposition methods and new chemistries, we have shown that these cells can be made at much lower cost, which would make them attractive for applications where efficiency is of utmost importance—like applications having limited area availability, such as (military) drones, automotive applications, and to enable soldiers to carry far fewer batteries in the field.

By pioneering new defect chemistries, interface control, and dopants, NREL recently demonstrated that cadmium telluride technology can achieve module efficiencies greater than 20 percent, upending decades of our common understanding of this technology. U.S.-

based First Solar is working with NREL to employ this innovation in their product. We believe that through material science, interface research, and device design advancements, we can achieve a target of 28 percent cell efficiency in coming years, which is a significant feat that could challenge silicon's dominance of the market and create a competitive advantage for the United States.

The Potential of Perovskites

The new materials and technologies we see before us today could lead to an accelerated renaissance in solar energy. Perovskite materials are prime candidates to fulfill this potential and are one of the most exciting areas of solar research today. Perovskites have demonstrated extraordinary progress in recent years, with the promise of increasing PV efficiencies while meeting lower-cost targets. NREL is a world leader in this technology, and we work with major academic groups and startup companies worldwide.

We have shown that solar modules from these materials could be produced by extremely rapid manufacturing processes such as roll-to-roll techniques. Imagine solar cells being produced at the rate of speed that a newspaper is produced on a commercial printing press. These materials can potentially also deliver very high efficiencies when employed in a tandem configuration—but again, produced using low-cost production methods.

We are optimistic that this potential revolution in PV technology could yield a tectonic shift in U.S.-based solar manufacturing. The time is right for creating a central hub for perovskite research, to solidify U.S. leadership in this area, by bringing together industry, universities, and national labs to empower a revolution in photovoltaic technology, and swiftly bring perovskites to commercial markets.

The EFRC and DuraMAT Research Collaboration Models

Successful solar research has often depended on strong collaborations, with support from the DOE Office of Energy Efficiency and Renewable Energy (EERE) and the DOE Office of Science programs at NREL. For example, Energy Frontier Research Centers have been and will continue to be pivotal in propelling solar energy into new territories. NREL has a major role in two EFRCs that have been transformative in their fields. The Center for Next Generation of Materials Design is led by NREL through a consortium with Lawrence Berkeley National Laboratory, SLAC National Accelerator Laboratory, and a series of universities. This EFRC partnership has pioneered advanced computational methods to discover new materials for solar energy conversion. Within the Center for Advanced Solar Photophysics, which is led by Los Alamos National Laboratory, NREL has discovered that quantum dot perovskites can be used as a top cell in new tandem solar devices, increasing their efficiency. Within the Solar Photochemistry core program, NREL discovered that under some conditions, perovskites can have extremely slow carrier cooling, potentially enabling ultra-high-efficiency solar cells without needing to create tandem structures. Clearly, Office of Science work funded through EFRCs and core programs are a successful model for technology innovation.

Another recently developed collaboration is the EERE-Solar Energy Technologies Office's DuraMAT program—a four-laboratory consortium led by NREL. Teaming closely with academia and industry, NREL, Sandia National Laboratories, Lawrence Berkeley National Laboratory, and SLAC are tackling the challenge of establishing durable materials for PV modules. DuraMAT's work includes identifying the types of stresses that a PV module encounters from the nanoscale to the module scale; investigating the installation and maintenance techniques that may affect degradation or failure; and developing an underlying understanding of resulting performance and cost ramifications. Again, fundamental science at multiple length scales and time scales is at the core of this important work to extend the life of solar modules and add value for the U.S. solar industry.

Storage for Solar Energy

As solar energy expands its reach, we will inevitably reach a point where storage technologies will be needed. Most of today's storage research focuses on utility-scale storage and batteries for electric vehicles. However, the technical requirements of storage for solar on homes, or for communities, differs considerably from these two areas. A complementary research agenda focused on new chemistries and materials could create scientific discoveries for new storage technology solutions that are needed for distributed solar energy.

Coupling storage with solar power also creates the ability to "island" the system—essentially isolating the individual system's generation capacity while still providing round-the-clock electricity. We're currently working with the Department of Defense on innovative solutions to power remote locations where no grid exists and where fuel is challenging, expensive, and dangerous to deliver. Another application is providing power when the grid is unavailable, such as during and after natural disasters that take down critical grid infrastructure.

Solar Integration Innovation

To have a reliable, resilient, and secure energy system in the United States—one that is second to none—we must integrate all the pieces of the energy puzzle. And that includes grid, load, generation, storage, controls, and operation. As distributed solar generation becomes a larger part of the generation mix, our electric grid systems have the potential to become even stronger, with greater flexibility and resilience. Energy integration at this complex level presents a deep scientific challenge—one in which intelligent control algorithms are being developed to operate in a cyber-secure, autonomous manner. With a dedicated effort from the DOE and the National Labs, this kind of autonomous energy grid could transform the electric system as we know it today.

Concentrating Solar Power

Concentrating solar power, or CSP, uses the sun's heat, rather than its light as in PV, to produce electricity. The cost of electricity generated by CSP has plummeted from 21 cents per kilowatt-hour in 2011, to about 10 cents in 2016. A unique feature of CSP technologies is that they can have built-in energy storage and still come in at an electricity cost of 10 cents per kilowatt-hour. In this way, CSP could provide grid operators the added flexibility in generation sources that they will need to manage an increasingly dynamic electric grid. To further reduce cost, additional breakthroughs and fundamental scientific understanding are critical. The primary challenge is to integrate a new, revolutionary thermodynamic system that operates at higher temperatures than the traditional system, but that yields substantially higher operating efficiencies.

During the last year, scientists and engineers at NREL, Sandia, and other National Labs worked closely with industry and academic researchers to develop a CSP Gen3 Roadmap. The roadmap identifies the R&D challenges along three pathways—molten-salt, solid-particle, and gas-phase receivers. All three pathways have the potential to achieve the goal of electricity at 6 cents per kilowatt-hour.

Solar for Fuels and Other Critical Needs

As solar power becomes more prevalent in the United States, we will have new opportunities to use surplus solar power in ways that will increase our power system's economic competitiveness. Solar-to-X refers to converting solar electricity or heat to something else of value, such as solar-to-fuels, solar-to-heat, solar-to-hydrogen, or solar-to-chemicals, such as ammonia. In addition to improving existing storage and demand-management strategies, cost-effective solar-to-X options could be used to help drive a resurgence in U.S. industry and manufacturing, with the attendant economic and job-creation benefits. This will require a sustained scientific research effort along each of these multiple pathways.

Solar energy conversion to fuels is still in the research stage, but holds great promise to contribute to future U.S. energy needs over the longer term. Several encouraging paths have emerged—for example, solar thermochemical, photo-electrochemical, high-temperature electrolysis, photo-thermal, and others. In particular, concentrating solar thermal systems and photo-thermal processes may be ideally suited for large-scale solar-fuel production, and they could significantly reduce electricity consumption for large-scale hydrogen production from water-splitting, as well.

Unleashing the Ultimate Potential of Solar

The power of the sun is naturally everywhere on Earth. If we're able to tap into that power anywhere, we would revolutionize how we make and use energy. Breakthroughs in solar-generation technologies that are lightweight, flexible, durable, and highly efficient will open the door for new, valuable applications. The concept of "solar everywhere"—on buildings, on vehicles, along roads, or built into equipment and devices—would be a game-changer for energy consumers everywhere. Based on current economic analyses, it is estimated that solar power costs could be reduced by two-thirds or more simply by integrating PV layers into the materials we use every day. Understanding how this can be done safely, efficiently, and cheaply is the challenge before us.

Recent breakthroughs in module-level power electronics, lower operating temperatures, and defect-tolerant materials such as perovskites that can be applied directly and rapidly to a surface, are making integrated PV an attractive option. One example is silicon panels. They are already being installed on trucks with refrigeration, reducing fuel consumption, and enabling trucks to run longer before batteries run down. Solar sunroofs are on a million cars across the globe. Thin-film PV technologies are being adapted to lightweight, flexible applications. Research suggests that there may be other, new, inorganic materials that are non-toxic and low-cost even at large-scale deployment, that merit further study. Each of these areas is ripe with possibility, and each will require dedicated research efforts to bring them to fruition.

In Conclusion

Fast-forwarding to 2050, current analysis suggests that U.S. electricity generation will be a widespread, bi-directional commodity that is valued through new market structures that put a price on location, use, and ancillary services provided by the power being produced.

The research concepts discussed here focus largely on energy-sector benefits to be gained from technological progress. That work takes on even greater importance when we consider one overarching fact: the United States is blessed with one of the best solar resources in the world. We would do ourselves and our children and grandchildren a disservice if we do not put this abundant and inexhaustible energy resource to work for us all.

There is still important early-stage research to do to improve cost, performance, reliability, integration, and applicability of solar energy. The U.S. can stay at the innovation forefront only with a continued federal investment. We should not underestimate the degree to which other nations are currently ramping up their own government-supported solar energy research efforts. If we fail to maintain our innovation leadership in this space, it is certain that others will be happy to take our place.

Without exaggeration, I can say that researchers at NREL and around the country are excited and eager to tackle the challenges ahead and to bring about the important advances in solar technology that we need for our energy future.

Martin Keller, Ph.D.
Director
National Renewable Energy Laboratory
Golden, Colorado
303-275-3011
martin.keller@nrel.gov

Martin Keller became the National Renewable Energy Laboratory's (NREL) director on November 30, 2015. NREL is operated for the U.S. Department of Energy (DOE) by Alliance for Sustainable Energy, LLC (Alliance). Martin also serves as the President of Alliance.

Martin joined Oak Ridge National Laboratory (ORNL) in July 2006 and was appointed to the role of Associate Laboratory Director in July 2009. In November 2010, he was asked to lead the newly-formed Energy and Environmental Sciences directorate. In this role he was responsible for the energy, biological, and environmental research programs supported by DOE, the Environmental Protection Agency, and the National Institutes of Health. Martin served as the Founding Director of the DOE BioEnergy Science Center and also served as the Director of the Biosciences Division.

Martin held a series of research management positions within Diversa Corporation, a publicly-traded biotechnology company. Martin joined Diversa Corporation in 1994 as a consultant to build and develop their microbiology expertise before joining Diversa Corporation full time in 1996.

Martin received his Ph.D. in Microbiology from the University of Regensburg, Germany.

Chairman WEBER. All right. Thank you, Dr. Keller. You were one second over. Dr. Eglash, you've got to get with the program. You're recognized for five minutes.

**TESTIMONY OF DR. STEVE EGLASH,
EXECUTIVE DIRECTOR, STRATEGIC RESEARCH INITIATIVES,
COMPUTER SCIENCE FOR STANFORD UNIVERSITY**

Dr. EGLASH. Chairman Weber, Ranking Member Rosen, Chairman Smith, Ranking Member Johnson, and Members of the Subcommittee, thank you for the opportunity to appear before you today.

There's tremendous benefit to continued federal investment in research in solar energy and other fields because this investment improves U.S. industrial competitiveness, strengthens our nation's economy, and creates jobs. Industry often can't afford this research on its own because the technologies are too numerous and broad, each individual project too risky, and in some cases the time to payoff too long.

Federally funded research must be appropriately focused and effectively managed if it is to lead to good return-on-investment and benefit for U.S. industry. Fortunately, we can turn to exemplary models and identify best practices. The U.S. government, academia, and industry each have unique roles and have to work together across the entire innovation pipeline. Government has the resources to fund research, act as a bridging institution, and convene across academia, national labs, and industry. Universities and national labs are excellent places for innovative research. Industry has insights on real-world opportunities and challenges, as well as the resources for commercialization and large-scale impact.

Recent progress in reductions in the cost of solar electricity has accelerated the deployment of residential and utility-scale solar. But as impressive as this is, it is only the beginning and there is a need to go further. Further reductions in the cost of solar electricity will lead to higher levels of penetration and will lower the average cost of electricity.

The next steps in solar panel research are higher performance through new and improved materials, larger panels leading to reduced cost of manufacturing and installation, reduced capital equipment costs for factories, and improved reliability for longer lifetimes.

Further DOE-funded research in solar energy is important for another reason. It is critical to U.S. competitiveness. If the U.S. develops technology for the next generation of improvements in photovoltaics, then we have an opportunity to expand manufacturing and increase jobs. If the U.S. doesn't do this research, then other countries will and they will reap the benefits instead of us.

The Bay Area Photovoltaic Consortium is an exemplary model for federally funded research. It was created in 2011 by the U.S. Department of Energy, Stanford University, and the University of California at Berkeley. The objective of the Bay Area PV Consortium is to perform industry-relevant, cutting-edge research on photovoltaic modules enabling high efficiency and low production costs, thereby strengthening the U.S. photovoltaic industry. The Bay Area PV Consortium established a new structure where industry sets the research priorities, professors at universities develop research proposals and conduct the research, and the DOE, academia, and industry work together to manage the program. The nature of the research is foundational to develop the knowledge base. It's not industrial policy, subsidies, or the government picking winners and losers. Rather, it's research that the industry will not undertake by itself because of the risk and time to payoff.

The Bay Area PV Consortium developed innovative technologies in close cooperation with industry that facilitated technology transfer and commercialization. It educated and trained a large number of graduate students and post-docs, thereby contributing to workforce development. The Bay Area PV Consortium created an interactive ecosystem comprising leaders from government, universities, national labs, and industry. The resultant interactions and collaborations catalyzed a generation of disruptive ideas.

The success of the Bay Area PV Consortium is due in part to a seamless integration of research and application that was responsive to the needs of industry, the ideas of researchers, and the priorities of the DOE. Of course, the BAPVC is just one piece of a larger research infrastructure where support for innovative and impactful research is contributing to our nation's success.

Federally funded research on technologies such as solar energy helps U.S. competitiveness and creates jobs. Continued U.S. Department of Energy funding for solar energy research will strengthen and expand the U.S. solar industry, reduce energy costs, and improve our energy independence. Public-private partnerships assure that federally funded research targets the right problems and results in successful technology transfer to U.S. industry.

[The prepared statement of Dr. Eglash follows:]

Statement of Stephen J. Eglash
Executive Director of Strategic Research Initiatives
Computer Science Department, Stanford University
to the
House Committee on Science, Space, and Technology
Subcommittee on Energy
Hearing on Advancing Solar Energy Technology
December 13, 2017

One-Page Summary of Testimony

There is tremendous benefit to continued federal investment in research in solar energy and other fields because this investment improves U.S. industrial competitiveness, strengthens our nation's economy, and creates jobs. Federally funded research must be appropriately focused and effectively managed, if it is to lead to good return-on-investment and benefit for U.S. industry. The U.S. government, academia, and industry each have unique roles and have to work together across the entire innovation pipeline. Government has the resources to fund research, act as a bridging institution, and convene across academia, national labs, and industry. Universities and national labs are excellent places for innovative research. Industry has insights on real-world opportunities and challenges, as well as the resources for commercialization and large-scale impact.

Solar energy performance and cost have improved dramatically in recent years, but there is a need to go further. Additional reductions in the cost of solar electricity will lead to higher levels of penetration and will lower the average cost of electricity. Further DOE-funded research in solar energy is important for another reason—it is critical to U.S. competitiveness. If the U.S. develops technology for the next generation of improvements in photovoltaics then we have an opportunity to expand manufacturing and increase jobs. If the U.S. doesn't do this research then other countries will and they will reap the benefits instead of us.

The Bay Area Photovoltaic Consortium (BAPVC) is an exemplary model for federally funded research. The objective of the BAPVC is to perform industry-relevant cutting-edge research on photovoltaic modules enabling high efficiency and low production costs, thereby strengthening the U.S. photovoltaic industry. The BAPVC established a new structure where industry sets the research priorities, professors at universities develop research proposals and conduct the research, and the DOE, academia, and industry work together to manage the program. The BAPVC was remarkably successful. It developed innovative technology in a close cooperation with industry that facilitated technology transfer and commercialization.

Federally funded research on technologies such as solar energy helps U.S. competitiveness and creates jobs. Continued U.S. Department of Energy funding for solar energy research will strengthen and expand the U.S. solar industry, reduce energy costs, and improve our energy independence. Public-private partnerships assure that federally funded research targets the right problems and results in successful technology transfer to U.S. industry.

Statement of Stephen J. Eglash
Executive Director of Strategic Research Initiatives
Computer Science Department, Stanford University
to the
House Committee on Science, Space, and Technology
Subcommittee on Energy
Hearing on Advancing Solar Energy Technology
December 13, 2017

Chairman Weber, Ranking Member Veasey, Chairman Smith, Ranking Member Johnson, and members of the Subcommittee, my name is Steve Eglash and I am pleased to share my perspective on advancing solar energy technology. I am a staff member at Stanford University where I am Executive Director of Strategic Research Initiatives in the Computer Science Department. I am testifying in my individual capacity and my views do not necessarily reflect those of Stanford University.

My career spans the fields of energy, materials, data science, and artificial intelligence. I have worked in small and large companies, venture capital, academia, and national labs. During 2007, I was co-leader of a solar energy strategic planning process for the U.S. Department of Energy and the National Renewable Energy Lab. During 2007–08, I was CEO of the solar energy startup company Cyrium Technologies. I have been at Stanford since 2010, where I am responsible for creating and managing research programs, often involving collaboration between industry and academia. I was one of the architects of the Bay Area Photovoltaic Consortium, an innovative collaboration between the U.S. Department of Energy, universities, national labs, and industry. The Bay Area Photovoltaic Consortium is led by Stanford and the University of California at Berkeley. I was founding Executive Director of Stanford's Energy and Environment Affiliates Program. I was Co-Chair of the SLAC National Accelerator Laboratory-Stanford Energy Task Force in 2014.

I was a speaker at the U.S. Senate Committee on Energy & Natural Resources Science and Technology Caucus in 2006. I presented testimony on the challenges and opportunities of the Internet of Things to the California State Assembly Select Committee on Emerging Technologies in 2015. I am a former Board member of the Materials Research Society, former Utilities Commissioner for the City of Palo Alto, and I am currently Chair of the Santa Clara University College of Arts & Sciences Leadership Board. I have a PhD and MS from Stanford and a BS from UC Berkeley, all in electrical engineering. I have four patents and more than 50 publications including a recent paper on the innovation process.

I. The Imperative for Federal Funding of Research

There is tremendous benefit to continued federal investment in research in solar energy and other fields, provided we follow best practices, because this investment improves U.S. industrial competitiveness, strengthens our nation's economy, and creates jobs. The federal government is uniquely well positioned to fund research, the results of which enable industry to develop new and improved products and services, achieve greater efficiency and operational excellence, and invent new business models. Industry often can't afford this research on its own because the technologies are too numerous and broad, each individual project too risky, and in some cases the time to payoff too long.

Federally funded research must be appropriately focused and effectively managed, if it is to lead to good return-on-investment and benefit for U.S. industry. Fortunately, we can turn to exemplary models and identify best practices. The U.S. government, academia, and industry each have unique roles and have to work together across the entire innovation pipeline. Government has the resources to fund research, act as a bridging institution, and convene across academia, national labs, and industry. Universities and national labs are excellent places for innovative research. Industry has insights on real-world opportunities and challenges, as well as the resources for commercialization and large-scale impact.

In fact, this triad of government, universities, and industry is one of our country's great strengths and it can lead to huge competitive advantage for U.S. industry.

II. The Need for Further Research in Photovoltaics

The U.S. Department of Energy's Solar Energy Technologies Office launched the SunShot Initiative in 2011 with the objective of making solar electricity costs competitive with other generation sources by 2020, without subsidies. The SunShot 2020 goal for utility-scale solar generation was achieved three years early in 2017. This is a terrific result because it has accelerated the deployment of residential and utility-scale solar energy.

As impressive as this is, it is only the beginning and there is a need to go further. The cost of photovoltaic-produced energy is now comparable to the cost of electricity from coal- or natural gas-fired power plants on a leveled-cost-of-energy (LCOE) basis, but these fossil-fuel power plants are dispatchable—that is, they provide power at any time whenever it is needed—whereas solar is not. Further reductions in the cost of solar electricity will lead to higher levels of penetration and will lower the average cost of electricity.

The next steps in solar panel research are higher performance through new and improved materials, larger panels leading to reduced cost of manufacturing and installation, reduced capital equipment costs for factories, and improved reliability for longer lifetimes.

Further DOE-funded research in solar energy is important for another reason—it is critical to U.S. competitiveness. If the U.S. develops technology for the next generation of improvements in photovoltaics then we have an opportunity to expand manufacturing and increase jobs. On the other hand, if the U.S. doesn't do this research then other countries will and they will reap the benefits instead of us.

As a utilities commissioner for the city of Palo Alto, California, which runs its own municipally owned utility, I learned firsthand the value of investing in solar and wind generation because the recurring cost of generating electricity using solar or wind is very low. All forms of energy production require an initial investment in plant and equipment. Natural gas, oil, and coal power plants require a continuing source of fuel, which is a major component of the cost of generating electricity from these plants. In contrast, the fuel for solar and wind power plants is free and the only recurring cost is operations and maintenance.

Of course, fossil fuel, nuclear, and hydroelectric power plants are dispatchable, whereas solar and wind plants require sunlight or wind. It turns out this is not a problem, because the ever-decreasing cost of solar and wind power generation coupled with technological advances are providing the means to use solar and wind generation to satisfy an increasing fraction of our energy needs. Batteries and other forms of storage allow us to store wind- and solar-generated electricity for later use. Load shifting enables some energy users to shift to times when demand is low and energy is plentiful. Technologies like concentrating solar power with thermal storage can provide solar power on demand, even when there is no sunlight. Most exciting of all, further advances in solar energy, catalysts, and chemical processes will lead to solar fuels, which are liquid fuels that can replace other chemical fuels in energy storage, energy generation, and transportation.

III. The Unique Roles of Government, Universities, and Industry

Different organizations are best suited for different roles in the innovation ecosystem. Government organizations like the U.S. Department of Energy can translate policy into action, weighing and balancing goals, assuring fairness, and protecting national interests. Government organizations can act as bridging institutions, facilitating knowledge transfer between those who conduct research and those who apply the results of research. Governments are uniquely suited to impose policies, standards, and incentives. They are also a major source of research funding.

Universities excel at education, intellectual scholarship, and workforce development. Many universities also excel at out-of-the-box thinking and developing innovative solutions. Industry can identify real-world opportunities, challenges, and constraints, thereby informing the research agenda. Industry can also enable large-scale impact by commercializing technologies and developing sustainable business models. Many companies also provide valuable financial support to university research programs.

Portions of this section on the roles of government, universities, and industry are from S.J. Eglash and S.M. Rizk, *MRS Bull.* **41**, 479 (2016).

IV. Bay Area Photovoltaic Consortium

The Bay Area Photovoltaic Consortium (BAPVC) is an exemplary model for federally funded research. It was created in 2011 by the U.S. Department of Energy (DOE), Stanford University, and the University of California at Berkeley. The objective of the BAPVC is to perform industry-relevant cutting-edge research on photovoltaic modules enabling high efficiency and low production costs, thereby strengthening the U.S. photovoltaic industry. The BAPVC is a novel and innovative collaboration between the DOE, the U.S. solar industry, universities, and national labs. The BAPVC established a new structure where industry sets the research priorities, professors at universities develop research proposals and conduct the research, and the DOE, academia, and industry work together to manage the program.

U.S. solar companies become members of the BAPVC by paying a membership fee and agreeing to contribute their expertise and perspective. These industry members are a critically important part of the BAPVC. In an advisory role, they identify research priorities, help set the research agenda, review and downselect proposals, review projects, and guide research. University researchers develop proposals, thereby preserving academic freedom. The DOE provides oversight and most of the funding.

The BAPVC developed innovative technologies in a close cooperation with industry that facilitated technology transfer and commercialization. It educated and trained a large number of graduate students and postdocs, providing them with an opportunity to interact and collaborate with solar industry leaders, thereby contributing to workforce development. The BAPVC created an interactive ecosystem comprising leaders from government, universities, national labs, and industry. The resultant interactions and collaborations catalyzed a generation of disruptive ideas. Companies praised the BAPVC for providing access to cutting edge technology and access to a highly trained workforce. Professors appreciated the real-world insights and paths to commercialization.

The BAPVC was remarkably successful. Representative research highlights include CdO transparent oxides, thin-film InP solar cells, ultra-thin silicon devices, perovskite/Si tandem cells, and light-trapping structures for CIGS thin-film devices. The BAPVC also developed technology roadmaps. U.S. solar industry companies were able to access advanced technologies and recruit a highly trained workforce. Those technologies enabled companies to improve device performance and reduce cost.

BAPVC researchers have produced 156 scientific publications, filed 12 patent applications, and received a large number of awards for their research. The BAPVC has trained 57 MS and PhD students and postdoctoral scholars who are now employed in industries such as solar energy, semiconductors, solid state lighting, wireless communications, data science, and the Internet. The BAPVC has resulted in technology transfer to industry in solar cell contact technology, new photovoltaic materials and structures such as perovskite materials and tandem solar cells, and characterization techniques like spectroscopic ellipsometry. The research has led to new research collaborations, new funded research programs, and collaborations between academic researchers and numerous small and large solar energy companies and large technology companies like General Electric and DuPont.

The success of the BAPVC is due in part to a seamless integration of research and application that was responsive to the needs of industry, the ideas of researchers, and the priorities of the DOE. The BAPVC incorporated sophisticated cost modeling to assure that technologies could be deployed cost effectively. As the program continued, in response to requests from the solar industry and the DOE, the BAPVC expanded its research focus to include research leading to reductions in capital equipment costs for PV manufacturing and improvements in solar cell lifetime in the field to 30 years and beyond.

The success of the BAPVC extends far beyond Silicon Valley. The BAPVC funded research at universities nationwide and worked with companies nationwide, leading to a geographically diverse and broad effort that provided benefits across the country. Of course, the BAPVC is just one piece of a larger research infrastructure where support for innovative and impactful research is contributing to our nation's success.

V. Conclusion

Federally funded research on technologies such as solar energy helps U.S. competitiveness and creates jobs. Continued U.S. Department of Energy funding for solar energy research will strengthen and expand the U.S. solar industry, reduce energy costs, and improve our energy independence. Public-private partnerships assure that federally funded research targets the right problems and results in successful technology transfer to U.S. industry.

Steve Eglash, PhD
Executive Director of Strategic Research Initiatives, Computer Science Department
Stanford University

Steve Eglash is Executive Director of Strategic Research Initiatives in the Computer Science Department at Stanford University and is part of the leadership team of the Bay Area Photovoltaic Consortium, a US Department of Energy-funded research organization. Steve develops and manages research programs in data science and artificial intelligence, bridging research and industry, including the Stanford Data Science Initiative, Artificial Intelligence Lab and its affiliates program, Secure Internet of Things Project, Stanford AI Lab-Toyota Center, and DAWN Infrastructure for Usable Machine Learning. These programs provide opportunities for deep engagement between industry and Stanford's researchers in big data, AI, IoT, security, autonomous vehicles, robotics, and machine learning.

Steve is a member of the advisory committee for the Stanford Center for Population Health Sciences. He was a member of the Stanford Computer Science Strategic Planning Committee (2017), Co-Chair of the SLAC National Accelerator Lab-Stanford Energy Task Force (2014), and a member of the SLAC-Stanford Energy Task Force (2011). Steve is an associate member of the National Academies Panel on multiple data sources. He was founding executive director of Stanford's Energy & Environment Affiliates Program and architect of the Bay Area Photovoltaic Consortium.

Prior to joining Stanford, Steve was president and CEO of the solar energy company Cyrium Technologies, consultant for the National Renewable Energy Laboratory and the US Department of Energy, venture capitalist at Worldview Technology Partners, vice president at SDL (JDSU), and member of the technical staff at MIT Lincoln Laboratory. As vice president at semiconductor laser company SDL Inc. Steve was part of the management team that grew the company to $1 billion in annual revenue and engineered one of the largest high-tech acquisitions in history. He has published more than forty papers in peer-reviewed journals and has four patents.

Steve received a PhD and MS from Stanford University, and a BS from the University of California at Berkeley, all in Electrical Engineering. He is a Fellow of the SPIE, a former Board member of the MRS, and a member of ACM, IEEE, MRS, OSA, and SPIE. Steve is chair of the Santa Clara University College of Arts & Sciences Leadership Board. He is a former Utilities Commissioner for the City of Palo Alto. Steve has been involved in humanitarian projects such as the Tech Museum Awards for Technology Benefiting Humanity.

Dr. Stephen J. Eglash

Executive Director of Strategic Research Initiatives, Computer Science Department
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University research administrator, industry executive, and technologist focusing on data science, energy, cleantech, optoelectronics, and materials with a strong technical background and experience in general management, data science applications, engineering, marketing and sales, venture capital, and the management of innovation.

Stanford University **2010 – current**

Executive Director of Strategic Research Initiatives, Computer Science Department. Executive Director of the Stanford Data Science Initiative, Artificial Intelligence Lab, Stanford AI Lab – Toyota Center for Artificial Intelligence Research, and Secure Internet of Things Project. Founding Executive Director of Stanford's Energy & Environment Affiliates Program. Founder and architect of Bay Area Photovoltaic Consortium.

Consultant **2008 – 2010**

Advisor to startup companies, venture capital firms, and universities in fields such as renewable energy, solid state lighting, and optical communications.

Cyrium Technologies **2007 – 2008**

President and CEO. Cyrium was a solar energy startup company developing high-efficiency solar cells for concentrated photovoltaic applications. Led successful Series B financing. Realigned product development R&D program and reduced cycle time.

National Renewable Energy Laboratory **2007**

Consultant to National Renewable Energy Lab (NREL) and U.S. Department of Energy. Led (with Sarah Kurtz) a strategic planning process for the NREL solar energy research program which addressed all aspects of NREL's program including the research portfolio, internal operations, IP policy, and industry interactions.

Worldview Technology Partners **2001 – 2007**

Principal. Responsible for venture capital investments in semiconductors, displays and imaging, power and energy, wireless, sensors, and basic materials. Also provided business development and operational guidance to portfolio companies.

JDSU (SDL prior to its acquisition by JDSU) **1993 – 2001**

Corporate officer and member of executive team leading to successful IPO and one of the largest technology acquisitions ever.

Vice president and general manager, Printing Business Unit. Achieved company-leading revenue growth and profitability.

Marketing manager, Pump Laser Business Unit. Managed a worldwide sales force of SDL employees plus distributors in 26 countries.

Marketing, product development, new product introduction, and manufacturing. Restructured product lines to narrow focus and improve profitability, negotiated key agreements with customers and vendors, and guided transfer of products from development into production.

M.I.T. Lincoln Laboratory **1985 – 1993**

Research staff member, Electronic Materials Group. Materials and device research for optoelectronic applications, including molecular beam epitaxy growth of GaSb-based alloys for semiconductor lasers and photodetectors. Co-inventor of new mid-infrared laser. Developed award-winning business plan for spin-off company to commercialize this device.

Hewlett-Packard Corp. **1974 – 1985**

Various positions at HP Labs and HP Microwave Semiconductor Division while attending high school and continuing through college and graduate school.

EDUCATION

Stanford University

Ph.D., Electrical Engineering **1986**

M.S., Electrical Engineering **1982**

Designed and executed experiments utilizing synchrotron radiation and molecular beam epitaxy to investigate the surface and interface properties of III-V semiconductor structures. Development of a novel GaAs Schottky barrier diode having tunable barrier heights. Ph.D. thesis: "Characterization and modification of Al-GaAs Schottky barriers." Advisor: Professor W. E. Spicer.

University of California, Berkeley

B.S., Electrical Engineering **1979**

AWARDS, MEMBERSHIPS, PUBLICATIONS, AND PATENTS

Former member of Board of Directors of the Materials Research Society, Fellow of the SPIE, and member of the IEEE, OSA, and ACM.

Worcester Polytechnic Institute Venture Forum Award (1992), with H. K. Choi, for a business plan for a new mid-infrared laser manufacturing company. Ross M. Tucker Electronic Materials Award (1985) from the American Institute of Mining, Metallurgical, and Petroleum Engineers.

50 papers published in peer-reviewed and other journals.

Four patents (U.S., awarded).

OTHER ACTIVITES

Chair of the Santa Clara University College of Arts & Sciences Leadership Board. Former member of City of Palo Alto Utilities Advisory Commission (2009 – 2016). Co-Chair of SenSys 2016 Conference and IEEE Data Analytics for Advanced Manufacturing Conference (2015 and 2016). Speaker at U.S. Senate Committee on Energy & Natural Resources Science and Technology Caucus (2006). Chair of SPIE Green Photonics Symposium and Photonics Innovation Summit. Involved in humanitarian projects such as the Tech Museum Awards for Technology Benefiting Humanity and the Global Social Benefit Incubator at Santa Clara University.

Chairman WEBER. You guys are good. Mr. Stein, you're up for five minutes.

TESTIMONY OF MR. KENNY STEIN,
DIRECTOR OF POLICY, INSTITUTE FOR ENERGY RESEARCH

Mr. STEIN. Mr. Chairman, thank you for the opportunity to participate in this Subcommittee hearing on federal government involvement in solar research. My name is Kenny Stein. I am the Policy Director for the Institute for Energy Research.

The purpose of federal government funding for research in any industry should be clearly defined. The justification for such funding is that research in emerging or novel technologies would not otherwise be provided by private interests, whether companies or individuals. This is a reasonable role for the federal government to play. However, this cannot be a license to spend money.

Federal support should not go to projects that private interests already have a clear incentive to develop. Far too often it is the case that the federal government provides grant money to companies to subsidize activities that they would already be undertaking.

A perfect illustration of this failure of mission is the SunShot Initiative. Launched by the Department of Energy in 2011, this move sought to reduce the cost of solar energy systems so that they could become cost competitive with other forms of energy. Simply put, that is a political goal, not a research goal. It is not the federal government's responsibility to support the success or spread of a given technology or way of operating. Any solar manufacturer or operator already has an overwhelming market incentive to lower costs. Offering government money in addition to existing economic incentives does not add to the well-being of the American people or address some unmet need of the federal government itself. It simply subsidizes activities which private interests are already doing. Indeed, government funding often crowds out private funding when it enters a given area, limiting the overall level of investment and spurring calls for even more government spending to make up for the exit of private investment.

The federal government, slow and process-constrained as it is, cannot adjust rapidly to technological developments. As new operating processes or products enter the market, it can be left funding old or obsolete initiatives. Getting locked in on lowering the costs of existing solar technologies does nothing to support emerging or novel technologies. Indeed, in another form of crowding out, this federal focus can lead an industry to spend its time trying to meet federal benchmarks rather than asking the question whether alternatives might make more sense, which ironically limits innovation in a given industry.

The SunShot Initiative has tried claiming victory as the costs of solar installations have indeed fallen. But how much of that cost decline is because of federal research spending rather than Chinese manufacturing innovation, tax support from the Investment Tax Credit, state renewables mandates, or the simple financial imperative to make money? The fact that is an impossible question to answer suggests the folly of the SunShot Initiative. SunShot was not about research. It was about picking winners and losers, arbitrarily seeking to improve the economics of certain solar applications because of the political preferences of the Administration at the time.

A more appropriate role for the Department of Energy can be found in the earliest days of solar energy generation technology. Early solar panels with poor efficiency found little uptake for terrestrial uses. However, the burgeoning space program identified solar as a potential energy source for spacecraft. Government funding from NASA helped develop nascent solar technologies to the point where it was usable in space applications. And years later, solar companies built on that foundation to develop the generation technologies that are now being applied to terrestrial electricity generation.

The lesson here is that the federal government didn't choose a solar technology and then try to commercialize it or reduce its costs. The basic technology was developed for a specific national purpose, with private innovation later finding applications for the private market. This is how the process should work. The federal government does not have the characteristics or competency to be a startup incubator, but it can effectively provide a base level of data and information for private innovators to build on.

Thus a better path forward for the Department of Energy would be focusing on the original mission that I suggested above, funding emerging or novel technologies and applications not otherwise supported by private interests. There is a legitimate federal role in supporting such basic research that has the potential to improve the overall well-being of the American people or is required to meet a specific federal need. The current Administration has indicated an interest in reorienting federal policies to early-stage research. I applaud this goal and look forward seeing how that initiative develops.

In closing, I will note, however, that this pivot should not just be a branding exercise, with anything called early-stage eligible for funding. Federal research spending should focus on truly novel technologies or applications. Further, this should not be a license to spend more money. Clearly focusing federal priorities means discarding some spending areas to hone in on truly basic research, a case where less is better.

Thank you for the invitation to participate in this evolving discussion.

[The prepared statement of Mr. Stein follows:]

IER INSTITUTE FOR ENERGY RESEARCH

Testimony before the House Science, Space, and Technology Committee – Energy Subcommittee

Hearing on: Advancing Solar Energy Technology: Research Trumps Deployment
Wednesday December 13, 2017

Kenneth Stein
Policy Director, Institute for Energy Research

Mr. Chairman, thank you for the opportunity to participate in this Subcommittee hearing on federal government involvement in the solar industry.

My name is Kenny Stein, I am the Policy Director for the Institute for Energy Research, a free-market organization which conducts research and analysis on the functions, operations, and government regulation of global energy markets.

The purpose of federal government funding for research in any industry should be clearly defined. The justification for such funding is that research in emerging or novel technologies would not otherwise be provided by private interests, whether companies or individuals. This is a reasonable role for the federal government to play; however this cannot be a license to spend money. Federal support should not go to projects that private interests already have a clear incentive to develop. Far too often it is the case that the federal government provides grant money to companies to subsidize activities that they would already be undertaking.

A perfect illustration of this failure of mission is the SunShot Initiative. Launched by the Department of Energy in 2011, this move sought to reduce the cost of solar energy systems so that they could become cost competitive with other forms of energy. Simply put, that is a political goal, not a research goal. It is not the federal government's responsibility to support the success or spread of a given technology or way of operating. Any solar manufacturer or operator already has an overwhelming market incentive to lower costs. Offering government money in addition to existing economic incentives does not add to the wellbeing of the American people or address some unmet need of the federal government itself, it simply subsidizes activities which private interests are already doing. Indeed, government funding often crowds out private funding when it enters a given area, limiting the overall level of investment and spurring calls for even more government spending to make up for the exit of private investment.

The federal government, slow and process-constrained as it is, cannot adjust rapidly to technological developments. As new operating processes or products enter the market, it can be left funding old or obsolete initiatives. Getting locked in on lowering the costs of existing solar technologies does nothing to support emerging or novel technologies. Indeed, in another form of crowding out, this federal focus can lead an industry to spend its time trying to meet federal benchmarks rather than asking the question whether alternatives might make more sense, ironically limiting innovation.

The SunShot initiative has tried claiming victory as the costs of solar installations have indeed fallen. But how much of that cost decline is because of federal research spending rather than Chinese manufacturing innovation, tax support from the Investment Tax Credit, state renewables mandates, or the simple financial imperative to make money? The fact that is an impossible question to answer suggests the folly of the SunShot initiative. SunShot was not about research; it was about picking winners and losers, arbitrarily seeking to improve the economics of certain solar applications because of the political preferences of the previous administration.

A more appropriate role for the Department of Energy can be found in the earliest days of solar energy generation technology. Early solar panels with poor efficiency found little uptake for terrestrial uses. However, the burgeoning space program identified solar as a potential energy source for spacecraft. Government funding from NASA helped develop nascent solar technology to the point where it was usable in space applications. Years later, solar companies built on that foundation to develop the generation technologies that are now being applied to terrestrial electricity generation.

The lesson here is that the federal government didn't choose a solar technology and then try to commercialize it or reduce its costs. The basic technology was developed for a specific national purpose, with private innovation later finding applications for the private market. This is how the process should work. The federal government does not have the characteristics or competency to be a startup incubator, but it can effectively provide a base level of data and information for private innovators to build on.

Thus a better path forward for the Department of Energy would be focusing on the original mission that I suggested above: funding emerging or novel technologies and applications not otherwise supported by private interests. There is a legitimate federal role in supporting such basic research that has the potential to improve the overall wellbeing of the American people or is required to meet a specific federal need. The current administration has indicated an interest in reorienting federal priorities to early-stage research; I applaud this goal and look forward seeing how that develops.

Note however that this pivot should not be just a branding exercise, with anything called "early-stage" becoming eligible for funding. Federal research spending should focus on truly novel technologies or applications. Further, this should not be a license to spend more money. Clearly focusing federal priorities means discarding some spending areas to hone in on research at, for example, National Labs or universities—a case where less is more.

Kenneth Stein

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Education

May 2011	**University of Houston Law Center** Juris Doctor Texas Bar #24079968 (January 2012)	**Houston, TX**
May 2005	**American University** Bachelor of Arts: International Studies University Honors Program 2001-2005	**Washington, DC**

Academic Honors and Organizations:
Association of International Petroleum Negotiators
International Baccalaureate Diploma recipient
International Law Society
Treasurer - Federalist Society

Publications:
-*Exxon-Venezuela Arbitration Dispute: Next Steps and Impact on Future Investor-State Disputes Under ICSID*, Journal of World Energy Law and Business, December 2011
-*The Solar Value Cliff: The Diminishing Value of Solar Power*, Co-author, August 2017
-Published articles available at:
www.freedomworks.org/users/kstein
https://instituteforenergyresearch.org/about/people/kstein/articles/
http://americanenergyalliance.org/energy-townhall/

Conference Participation:
August 2017 – State Policy Network Annual Meeting
-Speaker, Panel titled: "What's Powering the Drive for Electric Vehicle Expansion?"
November 2017 – Institute for Energy Research-Heritage Foundation Event
-Speaker, Panel titled: "The Department of Energy's Grid Resilience Proposal: Examining Impacts on Consumers and Energy Markets"
December 2017 – American Legislative Exchange Council State and Nation Policy Summit
-Moderator, Panel titled "Carbon Taxes"

Work History

August 2017 – Present	**Institute for Energy Research** **Director of Policy**
August 2017 – Present	**American Energy Alliance** **Director of Policy and Federal Affairs**
April 2017 – July 2017	**American Legislative Exchange Council** **Director** Director of the Energy, Environment and Agriculture Task Force.
June 2016 – February 2017	**FreedomWorks** **Consultant** November 2016 – February 2017 **Foundation Program Manager** June 2016 – November 2016
January 2016 – May 2016	**Ted Cruz for President** **Policy Advisor**
January 2013 – January 2016	**Office of Senator Ted Cruz** **Legislative Counsel** July 2013 – January 2016

	Agriculture, Energy and Natural Resources, and Environment and Public Works Committees.	
	Legislative Correspondent January 2013 – July 2013	
June 2012 – December 2012	**Houston Field Director**	**Ted Cruz for Senate**
January 2012 – June 2012	**Contract Attorney**	**Donovan and Watkins**
June 2010 – August 2010	**Summer Intern**	**Lewis, Brisbois, Bisgaard, and Smith**
May 2008 – August 2008	**Surrogate Operations**	**Republican National Committee**
January 2008 - May 2008	**Volunteer** (various)	**John McCain 2008**

Chairman WEBER. Thank you, sir. The Chair will now recognize himself for five minutes. Mr. Simmons, how specifically has the DOE changed its priorities to fund more early-stage research and technological development?

Mr. SIMMONS. In the areas that I outlined, it makes sense to spend money, say, on concentrated solar power for the value that it can have to grid reliability for things like power electronics because power electronics are really the bridge between power cells and the electric grid, and better power electronics can help provide important services to the grid.

So those are two ways as well as working for solar forecasting to make sure that we're focused on these—making sure that we have better solar forecasts so that solar is better integrated into the grid.

So it is making sure that we focus very much on this, you know, earlier stage projects and less on deployment.

Chairman WEBER. All right. Thank you. Dr. Keller, you've heard the Department's announcement to focus more on early-stage research within EERE.

Dr. KELLER. Yeah.

Chairman WEBER. Okay. So what impact could this refocus have on the direction and projects undertaken at your lab?

Dr. KELLER. So as I outlined in my testimony, we have a lot of early-stage research going on. So I applaud the department for focusing on the early stage. This said, I think it's also important that we have a balanced portfolio. I think it's very important that we looking into this holistically into this research because you need to look at this in an integrated way. So I think we need to continue to throughout early-stage research to de-risk some of these new technologies what industry cannot do. And then you also have to have a research portfolio to help to transition this technology to industry.

Chairman WEBER. You mentioned several areas of fundamental science in your testimony.

Dr. KELLER. Yeah.

Chairman WEBER. Can you explain how these areas help the solar industry?

Dr. KELLER. I give you perovskite as an example. This is a very early-stage research. If we are successful to overcome some of the limitation on this material, their stability concerns, for example, and moisture sensitivity, this will lead to a revolution in the way we're making solar cells.

So I showed you this, that you can use the so-called roll-to-roll. You can produce solar cells in the way you're doing newspapers because this will lead to an ink. So suddenly you can have solar panels in ways, in areas where we even have no chance right now to go into.

So this is one of this what I call game-changing technologies.

Chairman WEBER. Not to mention the rapid production.

Dr. KELLER. That's exactly what this is, roll-to-roll. So you—it's almost like an ink. So you bring this down to a carrier like you would bring down ink onto a newspaper. This can be revolutionary in the way of making solar panels.

Chairman WEBER. Sure. Mr. Stein, you talked about the proper role of federal government. So in your opinion, what is the proper role of the federal government when it comes to funding priorities for applied energy research?

Mr. STEIN. Well, I think the category that I sort of outlined is the idea that this is something that is not being funded and will not be funded by private interest or individuals.

Chairman WEBER. Well, should we preempt that with the need for it first?

Mr. STEIN. Well, the need for it—I think that——

Chairman WEBER. You have to have a need before you decide you want to go and research how to fix that need. True stuff?

Mr. STEIN. Well, that's, well, yes. That's certainly true. But the part of the problem with the government funding all these things is knowing what that need is.

Chairman WEBER. Right.

Mr. STEIN. The government isn't necessarily good at identifying those things.

Chairman WEBER. Heck, you say.

Mr. STEIN. You could have private companies can think of novel applications for some of these things that the government just doesn't have the capacity or the management process to come up with those.

Chairman WEBER. So when that need's identified, when that process is identified, should the federal government fund late-stage consortiums where industry is already involved in developing solar energy technology?

Mr. STEIN. Well, I would say no, simply because once it's already—the technology is proven once the data and research is there. Really, it's private companies going out and finding a way to economically produce that and apply it in the private market.

Chairman WEBER. Thank you. I've got about 30 seconds left, and I want to just make a couple of observations. I think there's about four steps to this. And Dr. Eglash, you may be the best one. You have the degrees in engineering, right?

It seems like there's four steps to solar: concentrate it, capture it, store it, and then release it efficiently. Is that fair?

Dr. EGLASH. Yes, that's fair.

Chairman WEBER. Okay. So where do you think—very quickly. I'm out of seconds here. But where do you think the most innovation needs to happen out of those four?

Dr. EGLASH. There's still a lot of opportunity for innovation in making solar panels better, more efficient, and lower cost and longer lived.

Chairman WEBER. So that's the storage part, that could release it efficiently?

Dr. EGLASH. That's the process of converting sunlight into electricity, the amount of electricity that we can produce for a given panel or a given dollar invested and then integrating that electricity with the rest of the electric grid with storage, with loads in buildings——

Chairman WEBER. That's the releasing it efficiently part?

Dr. EGLASH. That's right.

Chairman WEBER. Thank you. Then I now recognize Ms. Rosen for five minutes.

Ms. ROSEN. Thank you. So many questions, but I'm going to focus a little bit on our national security and safety, our dependence on foreign sources of energy, and the jobs that would be lost if we lose this industry.

So as a matter of national security and safety, we want to reduce our dependence on foreign sources of energy, reduce our carbon footprint, and the solar energy industry provides good-paying jobs.

Last year, there were over 260,000 solar workers in America, over 8,000 in Nevada. Jobs, of course, vary from installation to installation, manufacturing, sales, development, our own local IBEW, Local 357 with apprenticeship programs to train future electricians to work on solar, wind, all kinds of future things.

So to all the panelists, I want to tell you at the end of the day what my constituents care about are two things, our national security and safety and their ability to get good-paying, forward-facing jobs of the future.

So if we cut this DOE, this proposal to drastically cut the funding, these loan guarantee programs that finance these large energy projects, especially in Nevada, how is that going to impact your research and our jobs and essentially our security if we rely on China for our solar energy?

Mr. SIMMONS. If I may?

Ms. ROSEN. Yes.

Mr. SIMMONS. One of the important things that we are doing is focusing on the early-stage research and development. What that means and what we want to do is that's not the end of the story. We do not want these technologies just to be developed in the labs and to stay in the labs. That's why I'm glad that Martin is here today because NREL has done a very good job of filling the next part, and that is for—what we would very much like, and we as the Department of Energy would like, is to then work with industry in making sure that we get those technologies out of the labs. So at the Department of Energy, there's the Office of Technology Transitions that works with that to help bridge that technology and get it out of the labs.

Also, in the labs, and Martin can speak to this, is that the labs can and do engage with industry and strategic partnerships. They do work for industry and very much we would like to bring more industry dollars to the labs to be able to get these technologies out of the labs and into the market, to grow the workforce so that we have more solar jobs in America than in other places.

Dr. EGLASH. If I could add something to Mr. Simmons' comment? I think it's important to realize that these technologies are not static and fixed in time. These are technologies that are evolving. And so even though there has been recent progress, there's still room for considerably more improvements in performance, cost, manufacturability, and reliability.

If America does this research, then we'll have the IP and know-how. We'll be in a position to translate that into stronger companies, a stronger economy, greater energy independence, and more jobs. If we don't do the research, someone else certainly will. The research is there waiting to be done, and then we won't have the opportunity to reap those benefits ourselves.

Ms. ROSEN. Thank you. I want to build on that because our critical grid infrastructure, it does rely on a combination of technologies. And how do you know what's early- or late-stage? Because like you said, things aren't static, they're dynamic. And sometimes you are doing research, you hit a dead end one time but that becomes a solution and the next research.

So please tell me, Dr. Eglash, can you discuss a false dichotomy between early-stage and late-stage research?

Dr. EGLASH. I think this distinction that some people like to draw between early and late stage or basic and applied is frequently misleading and not helpful. What's needed in most cases is understanding fundamentally what's going on in areas that can be inspired by and informed by real-world problems.

That's why having the federal government and industry and our scientists and professors all involved in this dialogue and this effort can be so helpful.

If we think of the future of the energy system, communications and information technologies and energy are frequently going to come together around things like smart cities, electric vehicles, and so on. We can't predict that trajectory. We want to make sure that we have the know-how in technologies to allow us to control it and benefit from it.

Ms. ROSEN. So we need those on-ramps and off-ramps through all stages of research and development to continue to grow in every single way, would you say?

Dr. EGLASH. I would say.

Ms. ROSEN. Thank you.

Chairman WEBER. She was right on the money, too. I tell you what. You all are going to spoil us. The Chair now recognizes Mr. Rohrabacher from California.

Mr. ROHRABACHER. Thank you very much, Mr. Chairman, and let me just note that I think that your testimony today is a reason for optimism. And we've actually had the government do some things that seem to be bearing fruit now. So that's great.

But the trouble is, and I will just have to say, whenever—Ronald Reagan used to say—and I'm wearing Reagan brown today by the way—Reagan used to say that a government program is the next best thing to eternal life on this planet. And Dr. Eglash, I'm sorry, but at some point, we've got to say the private sector can do this. And I certainly buy onto the evidence that we've heard today that we have made great advances so that we now know there are billionaires in the private sector who could put money into this and make it real. The idea that you did suggest, however, which I thought was important, was there are government policies—now that it is real, now that it can be commercialized, that we need to make sure that the government policies of how to get onto the grid—and in fact, there's big debates here over the years as to whether or not the electric companies should be forced to take electricity when it's being produced by a private sector, and thus we would be able to give incentives for even more solar energy production of electricity. I've always thought that was a fairly good idea myself.

I'd like to ask you guys about—and I say all of you. I've heard that there's a major technology breakthrough in batteries, and I understand that there's been a lot of money put into it and various approaches. But that at the University—Mr. Chairman, your university down in Austin, Texas, I understand has had a breakthrough with the fellow in charge of the—I think he was the inventor of the lithium battery, Dr. Goodenough. Now, he says, and what I understand, is that now they're capable of producing a type of battery that would be based on sodium rather than lithium. Have you heard about that? And if you have, does that have promise or is there something wrong, it's just being hyped? Maybe a little bit from each one of you on that.

Mr. SIMMONS. Sure. So the Department of Energy, we fund research on batteries for—a wide variety of batteries, that we do not want to put all our eggs in one basket when it comes to battery technologies because of, you know, the value of energy storage, both for automobile applications, which is one of the areas where we fund research and the Office of Electricity funds research for grid scale storage.

So we fund a large number. I have heard about this technology.

Mr. ROHRABACHER. You don't have any——

Mr. SIMMONS. I don't have—I don't know any specifics.

Mr. ROHRABACHER. Okay. Yes.

Mr. SIMMONS. But there is great opportunity.

Mr. ROHRABACHER. Okay.

Dr. KELLER. You know, Professor Goodenough, is as you said, godfather of lithium.

Mr. ROHRABACHER. Right.

Dr. KELLER. So the technology you're describing I think is very exciting. It also depends on batteries and what applications are using batteries. The design of batteries are very different if you're going to automotive or if you go for example——

Mr. ROHRABACHER. Have you heard anything about the sodium battery?

Dr. KELLER. Yes. Yes, I saw——

Mr. ROHRABACHER. Thumbs up or thumbs down?

Dr. KELLER. I think it's thumbs up. So the key is there's energy density thing we have to work on.

Mr. ROHRABACHER. Okay.

Dr. KELLER. But overall, I think it's very encouraging.

Mr. ROHRABACHER. Okay. Thumbs up? Thumbs up or thumbs down on Goodenough's sodium battery?

Dr. EGLASH. I wanted to put it in the broader context, echoing what some of the previous witnesses have said. The improvement in battery technology is dramatic and continuous, and it's going to help storage for electricity on the grid as well as automobiles.

Mr. ROHRABACHER. That's clear. Now, what about this sodium breakthrough?

Dr. EGLASH. Very promising.

Mr. ROHRABACHER. So you give it a thumbs up as well?

Dr. EGLASH. Sure.

Mr. STEIN. I'd give it a thumbs up as well. It's always new breakthroughs are wonderful to hear about. The one thing I'll just highlight is that battery and storage technology I think is an example of something that—the private sector already has a very enormous incentive to already do this. So I think that's one area that we can think about backing off federal funding.

Mr. ROHRABACHER. So you gave it a thumbs up. So we've got three thumbs up and one not so sure but maybe. And let's just note again—and I agree with the last witness who said we put in, somebody put a lot of money into that research. And I know that it's a little basic and applied. I understand your point there. But definitely the basic research has been done, and it seems to me that we should be applauding anybody who invests in things like Dr. Goodenough's new sodium battery. And we should, Mr. Chairman—I would hope the job of—our job is to see what we can to goose the private sector into investing in it and to actually commercializing some of these breakthroughs like Dr. Goodenough has done at the University of Austin in Texas. Thank you.

Chairman WEBER. Well, I'm not sure the right word is goose the private sector in this setting. Maybe it's charge the private sector with getting that done. Maybe that's a better word. The Chair now recognizes Mr. Veasey of Texas.

Mr. VEASEY. Thank you, Mr. Chair. And I wanted to ask questions to Dr. Eglash and Dr. Keller. The President's budget request declared some research as early stage and therefore worthy of federal support. Other activities, such as later-stage research, also should be immediately eliminated, according to this, given that the private sector's supposedly better equipped to carry them out. However, Administration officials confirm 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 or willing to pick up.

In your experience, I wanted to know, are the cuts proposed in the fiscal year 2018 budget research areas of the private sector is willing to simply start funding after the federal government cuts them?

Dr. EGLASH. The private sector is in most cases unable and unwilling to make up for those cuts for a number of reasons. Much of the research that still remains to be done is across diverse technologies and risky and very difficult for any single company to justify investing in.

In addition, the balance sheets of most U.S. solar energy companies are not strong enough right now to support the level of investment that would be needed to bring solar energy to the next level.

As you know, government has a long tradition of helping to support technologies like energy in particular where the costs of projects and the time to pay out can be quite long.

Dr. KELLER. So I think the problem that I'm seeing is was the industry taking over. But you have to understand, where is the new technology? Let's come back to the battery example. If somebody invents a new anode or new cathode which is really promising, the way that you bring this to market is a long, very risky process. And I think this is where we from the research community can work together with companies to deal with some of this technology to further move it down the market.

If this is a tiny little improvement, I would agree that this should be done by industry. But if you have some game-changer, so for example, you go from lithium to sodium, this is not just done overnight. So this is a very risky and a very long process. And I think we need to have a balance there to help industry to deal with some of this technology, to move it further down the market.

Mr. VEASEY. So I mean with that, do you think the federal government should engage with stakeholders in the private sector to understand what research areas they're likely to fund before it proposes to completely eliminate or drastically reduce funding for R&D programs?

Dr. EGLASH. I think there's huge benefit to the kind of dialogue with industry you're describing. I think that industry has the real-world experience and perspective and insight that can help inform the research agenda. I think also the fact that we're arguing for federal funding, it's also true that industry should have some skin in the game. This doesn't need to be in the spirit of handouts, and of course, many of these federal programs involve different models for cost sharing. And that can be one of the best practices for doing this kind of thing.

Dr. KELLER. Another example is if you look at industry, I think industry is very, very good to take current products and fine optimize the current products, but I think a lot of times you don't see that industry is changing and doing the step function.

So I'll give you this example from my prior job, and we started this idea to what about if you would 3–D print the whole car. Current automotive industry would not do this because it potentially disrupts the whole business models. So but now when you show that research is opening up this venue, then you come, you bring—then work with industry and then help to transition this new technology, this 3–D printing over which can completely change the way we're doing molding, for example.

So this is an example where I think there's a very good synergy by de-risking and helping to push technology into the market and keeping U.S. companies competitive because a lot of this research innovations goes on around the whole world. And we here in the U.S., I think we are the world champions in innovation. And I think we have to continue to drive innovation forward, to keep our U.S. companies on the forefront of innovation. And I think this is what the federal support to research can do.

Mr. VEASEY. Thank you. Mr. Chairman, I yield back.

Chairman WEBER. I thank the gentleman. I now recognize the gentleman from Florida, Mr. Dunn, for five minutes.

Mr. DUNN. Thank you very much, Mr. Chairman. We have so little time and so many questions. I'll try to be brief, and I urge you to do the same.

Dr. Keller, first up. In your testimony, you explained the multi-junction solar cells that are in the satellites, too expensive for terrestrial applications but you're trying to bring them back to earth. What are the material structural properties of these cells that are so desirable? Briefly.

Dr. KELLER. So very briefly, it's almost like a sandwich. You're stacking all the different materials on top of each other, and the way we're doing this right now is very expensive, to lay down all this material, make the intermediate. So the idea really is how to bring the technology we have running around on Mars, how do we bring this back on Earth? And this is where we need new innovation to make this next step of the manufacturing. And that's again what I talked about——

Mr. DUNN. So it's a manufacturing thing?

Dr. KELLER. The process of the multi-junction cells will stay the same, but the way we make it, we have to make it in a much cheaper way to put this onto our drones——

Mr. DUNN. Okay. That sounds promising.

Dr. KELLER. —and satellites.

Mr. DUNN. Could you describe the advancements in battery again, Dr. Keller, battery sciences, and are there actually batteries now or in the near-term future that are capable of meeting utility-scale power demands?

Dr. KELLER. So my personal opinion is that again, what I tried to say earlier, that batteries are not batteries. So there's a difference on the architecture. If you're going to a battery into a car, where's the battery for grid? Because as you know, when you drive around, you're limited on space what you can put into a car. So when you have very high-energy density, you want to try to do it as light as possible.

On the grid side, well, a lot of times room is not necessarily the limitation——

Mr. DUNN. But I mean, even a battery of size, there's room.

Dr. KELLER. Yeah.

Mr. DUNN. Utility scale? Really?

Dr. KELLER. So I think we can and I think also I would say the batteries would depend on what the application is. Will we have batteries for two weeks of storage, you know, at grid level.

Mr. DUNN. When you say two weeks of storage, megawatt hours, day in, day out, for 2 weeks?

Dr. KELLER. So I think we will—with different—with certain technologies in batteries, we will go to a grid-level storage possibility.

Mr. DUNN. I'm intrigued. So I'm always—again, Dr. Keller, the potential for solar fuel. What fields—and I will say, I'm always puzzled that I never—I had this dearth of reporting of research on hydrogen. It seems like such a simple ladder, you know, to electrolysis, hydrogen. Am I missing some key?

Dr. KELLER. No, you're absolutely correct. When you forecast where the electricity costs might come in the years, it might be that the electricity is getting very plentiful. People might argue it might get so cheap that it's not worth—anymore.

So the key is what are we doing with electrons? So the idea is can I take electrons to something else? So you can call this power-to-x, for example.

Mr. DUNN. Well, I mean, if you can make a lot of hydrogen——

Dr. KELLER. This——

Mr. DUNN. —you can store that.

Dr. KELLER. You could do this.

Mr. DUNN. Right.

Dr. KELLER. Or you could go through hydrogen as a platform molecule to hydrocarbons. You can use hydrogen to go to ammonia.

Mr. DUNN. Or you can just burn it.

Dr. KELLER. So the idea is can you diversify electrons? And we are doing more with electrons, just putting them into the grid. So this is I think where we need research and very fundamental research——

Mr. DUNN. Storage?

Dr. KELLER. —to go down this path. Yes.

Mr. DUNN. But it just looked like an obvious one to me. I'm going to turn to Mr. Stein, if I may. I want to focus now on the market forces that have decreased the cost of photovoltaic solar energy. Do you think that's basic science research that's had the major impact or is that just innovative manufacturing or perhaps it's government fiddling with tax credits?

Mr. STEIN. Well, as far as lowering the cost itself, there's no question that that has happened. And that's, I mean that's certainly to—it's incentivized by the tax credits. But that probably would have happened independently of that. But the largest portion of it is almost certainly is Chinese manufacturing innovation because that's why the solar panels have become so much cheaper is really because they're being imported from China.

Mr. DUNN. And they're probably subsidizing the manufacture. Is that your point?

Mr. STEIN. Well, they probably are subsidizing at least a portion of the manufacture but it's also just they have cheaper labor, they have lower environmental standards, frankly, because some of the components that go into some of these solar panels——

Mr. DUNN. I'm going to interrupt you. We're running out of time. If there were no tax benefits to solar, no investment credits, no mandatory buybacks, all this stuff, what would—would solar be economically viable and what do you imagine a megawatt hour would cost if you could guess that?

Mr. STEIN. I think it would be economically viable in certain parts of the country. I think Southern California?

Mr. DUNN. So—yes.

Mr. STEIN. It makes a lot of sense. Massachusetts, it doesn't.

Mr. DUNN. So, within range. In the 30 seconds left to me, Mr. Simmons, you mentioned grid integration reliability issues, the duck curve. Could you describe EERE's focus on utility scale demand, and is the storage of energy part of that focus? If so, how?

Mr. SIMMONS. At EERE, we are focused not on the utility scale storage so much. That is really the Office of Electricity at the Department of Energy. However, we work together with the Office of Electricity through the Grid Modernization Initiative to bring together both of our offices to be able to look at all types of storage, whether it is storage at home, storage on the grid——

Mr. DUNN. The truth here is that I've exceeded my time. And as we all know, our Chairman is very capable of telling time. I won't push my luck any further. Thank you very much for all of the panelists. Mr. Chairman, I yield back.

Chairman WEBER. Mr. Simmons, would you like to finish that answer for him?

Mr. SIMMONS. I'll just finish by saying that we are working together with the Office of Electricity to look at grid-scale storage using a variety of different storage techniques and thinking about the issue holistically as well as being able to look at integration of building technologies with the grid to be able to hopefully shift some demand around, reduce peaks. You know, really, when it comes to storage, I think it's important to think about storage holistically and everything that we can do to shift around demand for energy to overall reduce the cost and really drive economic growth.

Chairman WEBER. I thank you. I yield the gentleman another 30 seconds?

Mr. DUNN. Well under 30 seconds. I'm going to ask the panelists, any of you who think you are capable of this, please, please, please get back to us with a white paper on storage. We are not informed well about storage. Thank you.

Chairman WEBER. I thank the gentleman. I now recognize the gentleman from California. Jerry, you're up.

Mr. MCNERNEY. Well, thank you, Mr. Chairman, my good friend in nuclear power. You know, I spent about 20 or more years in the wind industry, some of it at NREL's National Wind Technology Center. Good times. We had developed a theoretical model that showed diminishing cost-of-energy return as the turbines got bigger, only to be shown later that that was wrong. So Dr. Keller, is there a similar theoretical curve for solar, a model for solar energy that shows diminishing cost-of-energy return for solar?

Dr. KELLER. Look, I don't know if a model like this exists because like now, we're seeing—and you might have a better idea there. But look, I think right now we're seeing further decrease in solar because it's a complex synergy of all this different technologies working together. But you might have——

Dr. EGLASH. If I may add a comment?

Mr. MCNERNEY. Yes.

Dr. EGLASH. Certainly for a solar cell built out of a single semiconductor, there are limits in its performance. And so one of the current areas of research is combining two different semiconductors together. We've heard a couple of people today talk about a new class of materials called perovskites, and one of the things that people are looking at as a so-called tandem cell that involves a layer of perovskites and a layer of something else that might in fact be silicon.

It's also true that solar cells don't always work well at high temperatures. And so there's work involved in trying to improve the performance of solar cells at high temperatures because they're often used in environments where obviously the ambient temperature can be quite high.

Mr. MCNERNEY. So there's significant room for improvement in cost?

Dr. EGLASH. That's right.

Mr. MCNERNEY. Thank you. Dr. Keller, Mr. Stein stated that government funding often crowds out private funding when it enters a given area. Have you seen government funding crowd out private funding in areas of NREL's research?

Dr. KELLER. No. Look, I think there's a synergy because when you have a strong, fundamental science portfolio with the people who understand also what industry needs, and when you look into this, a lot of our research when we go— perovskite is a good example. I mean, you're doing a lot of analysis up front to see what is really some of this new game-changing technologies based on some of the analysis. And of course, a lot of the fundamental science also has input from industry where a lot of our researchers not just create it out of a vacuum. You're having committees, you're having panels. You're inviting the top researchers and getting feedback.

So I would argue that there's nice synergy by having a strong fundamental science and then you're tying all of this with industry. And this is where you then get the synergy and the most advancement of the technology.

Mr. SIMMONS. May I make a quick——

Mr. MCNERNEY. Sure.

Mr. SIMMONS. —comment about that? In terms of the Administration's position here, we want to spend, you know, limited taxpayer—you know, some of the limited taxpayer dollars that we have on early-stage research. However, we also want very much for this work that Martin was just talking about as this synergy between the national labs, we want to leverage the investments that have been made at the national labs through taxpayer dollars and then leverage that with NREL, the other national labs also working together with industry to get those out of the labs.

So that work that he was just talking about, I want to stress that the Administration very much supports that.

Mr. MCNERNEY. I'd like to believe you. Dr. Eglash, can you explain why the companies in the Bay Area PV Commission don't carry out research in certain areas that might actually benefit their long-term bottom line?

Dr. EGLASH. You mean on their own?

Mr. MCNERNEY. Right.

Dr. EGLASH. Yeah. There's a number of reasons. One is that in many cases, they simply don't have the financial wherewithal to do so. And to your earlier question about whether federal support might crowd out private investment, I think we can point to several examples where the opposite is true and federal support actually attracts increased private investment because at that point there can be a leveraging of the investment and you can reduced some of the barriers that the private sector would otherwise see.

In the case of the companies that have chosen to join the Bay Area PV Consortium, they're contributing cash alongside of the federal investment. They're also contributing know-how and insights, and they also provide a path to commercialization for the innovative technologies that are being developed.

So far from being a handout, the idea is much more of a partnership.

Mr. MCNERNEY. Kind of a leverage to get industry to invest more.

Dr. EGLASH. I think there is definitely a leveraging.

Mr. MCNERNEY. Thank you, Mr. Chairman. I yield back.

Chairman WEBER. I thank the gentleman. I now recognize Mr. Tonko for five minutes.

Mr. TONKO. Thank you, Mr. Chair, and welcome to our witnesses. I'm pleased that the Committee is looking at this issue, and I strongly believe that we must continue to support and fund renewable energy research. The Office of Energy Efficiency and Renewable Energy has a proven record of delivering innovative technologies that make renewable electricity generation cost competitive. As we push our innovation economy forward, groundbreaking new technologies become that much more essential.

EERE allows exactly these kinds of technologies to take root. I could not be more proud of these first-of-their kind and game-changing new technologies that this program is helping to make a reality. In 2011, through the SunShot Initiative, we set out to reduce the total cost of solar energy. We set ambitious goals, and we invested wisely. This past September, the SunShot Initiative successfully met the utility scales solar cost target of 6 cents per kilowatt hour three years earlier than anticipated.

While we should herald this success, I worry that there are interests who would have us reduce our commitment to renewable energy research. China currently invests more than double the U.S. commitment to renewable energy research and development; and while other countries continue to pioneer innovative renewable energy and hyper-efficient technologies, President Trump and Republican leaders are working to eliminate or gut most cutting-edge programs including Advanced Research Projects Agency-Energy, the ARPA–E, and the Office of Energy Efficiency and Renewable Energy. The budget proposed by the President would cut funds for EERE by 70 percent and eliminate ARPA–E entirely. These massive cuts defy common sense and will cost us dearly in the future by abandoning innovation and weakening America's global competitiveness.

So we must do more to support these groundbreaking initiatives. We've heard that the SunShot Initiative is a political goal, not a research goal. However, it seems to me that the purpose of investments in energy technology are to advance the technology so it functions more efficiently.

So Dr. Eglash, could you explain why the SunShot goals were a completely reasonable choice for focusing government investment?

Dr. EGLASH. The SunShot goals created an inspiring target of cost and performance that then mobilized the attention of researchers and industry. At no point did it seek to pick particular winners and losers beyond a support for solar energy.

If I could just comment briefly, for several years I was a utilities commissioner for one of our nation's small municipally owned utilities, the utility of the City of Palo Alto, California. And there through purchasing and deploying utility scale solar, we were able to reap the benefits over years of a technology that doesn't need a continuous source of fuel, like gas or coal or oil. Once you've deployed it, it's then free, other than a modest operations and maintenance cost. And in that same way, the nation's increasing use of solar and renewable energy can help strengthen the grid and provide greater energy independence.

Mr. TONKO. Thank you. Dr. Keller, can you tell us a little more about how the SunShot Initiative contributed to falling prices in solar energy?

Dr. KELLER. The SunShot looked at this holistically, how you can drive down costs through more innovation research. And when you look at this in what areas research was done just to name a few, it was in general about the efficiency of the materials, the position of these materials, a better understanding of the photo absorbers such as silicum or cadmium telluride, the buffer layers, the electrodes, the new module materials, power electronics.

So it was not one little step which led to this. It was holistically, that you're looking into all the different components to further create research and innovation to further decrease cost. And I think it was very successful, and people say it was all done by China. I would like to compare this to when you look at First Solar, which also—the biggest U.S. manufacturer of solar panels—and they also with cadmium telluride decreased the cost significantly here in the U.S. because of some of this research going on in activities such as SunShot.

Dr. EGLASH. If I may add a specific——

Mr. TONKO. Sure.

Dr. EGLASH. —example to the story, the way that this worked was industry would identify certain needs, needs for lower manufacturing costs, needs for example for a better encapsulant, the coatings that keep humidity away from the solar cell itself. But they wouldn't propose what the particular solution would be. That came from the researchers. And while it's not clear whether you can call that basic or applied, it is clear that with the help of EERE and the SunShot goals to focus attention, we were able to have that kind of synergy and leverage between identifying problems and then finding promising solutions.

Mr. TONKO. Which would obviously increase our competitiveness as an American solar industry. Gentlemen, thank you very much. And with that, I yield back.

Chairman WEBER. I thank the gentleman. The gentleman from California, Mr. Takano, is recognized.

Mr. TAKANO. Mr. Chairman, thank you. Mr. Simmons, we've heard that the SunShot Initiative may not have been responsible for the cost of solar installation's falling as the cost decline may have largely been the result of Chinese manufacturing innovation. However, China has invested over $50 billion in renewable energy investments since 2012 and upwards of $100 billion recently. During that time, China has become the world leader in solar panel manufacturing. I think we can agree that the investments in China are overwhelmingly made by the Chinese government.

While you discussed the importance of the free market, the countries we are competing against in this industry do not seem inhibited from using government investment to throw the game in their country's favor. Do you believe that there may be a government role in avoiding ceding control of this vital industry to China?

Mr. SIMMONS. I—you know, it's the Administration's position that there is a government role for early-stage research and development.

Mr. TAKANO. Okay. So you do believe there's a government role?

Mr. SIMMONS. Well, I mean, that is the Administration's position.

Mr. TAKANO. All right. And we've heard that—you've heard the discussion about how that's not so easily defined, about what early stage is——

Mr. SIMMONS. Sure. Sure.

Mr. TAKANO. —versus and that's a legitimate point for discussion. Does anyone else want to—I mean, Mr. Keller or Mr. Eglash, would you like to comment?

Dr. EGLASH. I just wanted to point out that the solar energy industry was largely created by the United States during research, going back 20 or 30 years. And it's only been during the last 10 to 15 years that much of the solar energy manufacturing industry has moved overseas, particularly to China. But with the evolution of these technologies, we have an opportunity to bring significant portions of that industry back to the U.S. with all the ancillary benefits of doing so.

Mr. TAKANO. Dr. Keller?

Dr. KELLER. May I just jump in there for a second? I fully agree with this comment and what I said, for example, on this next generation of materials. If he is successful to keep and drive this innovation forward, this is also a chance in my opinion to get the supply chain for all solar manufacturing back into the U.S.

Mr. TAKANO. So this next generation of materials, do you think that's something that's left to the free marketplace or—vis a vis our competition with global competitors? Is this early stage? It's really not early stage.

Dr. KELLER. Perovskites are still very early stage, but I'll tell you what's happening right now that we are in the U.S., I think we still have a front, a leading position in this new next generation of materials. But they say, everywhere I travel, people jump onto this like crazy, and our fear is that China for example starts to invest significant more money in this next generation of materials. And so the key is we have to continue to drive this innovation and not only on the material side but then you're combining this with the next generation of manufacturing side.

Mr. TAKANO. How do you answer folks who, you know, who say that government's really not good at job—does not do a good job of deciding these sort of things? It seems to me that there might be some market incentives for people to invest in this research. I mean, how do you answer that?

Dr. EGLASH. There certainly are market incentives in some of these areas. But we're living in a particularly promising moment with respect to material science, chemistry, and chemical engineering. These are technologies that can help solar energy, energy broadly including storage, and a variety of other technologies.

While there is a vibrant materials and chemistry industry today, it's not sufficient in and of itself because these technologies are so broad and so many of the hugely promising things we could do are risky enough, diffuse enough, or have a sufficiently long time to pay off that we'll be in an even better position if we also have some federal support for research and materials and chemistries.

Mr. TAKANO. Go ahead, Mr. Keller.

Dr. KELLER. If I can jump, when you look at perovskites, what's happening right now is an example which was at the beginning very risky. Now we're getting to this point where people say, oh, this could be really exciting. Now we're seeing interest from certain start-up companies. They're coming out of Stanford. They're coming to us. They're trying to collaborate with our scientists to advance this technology, and I think this is an example where when you start how all this was initiated came from very, very early stage research, then was narrowed down. We tried to overcome some of the big principles around these materials. And so this leads in my opinion, if you continue to drive this innovation forward, will have the potential to revolutionize solar.

Mr. TAKANO. We might be missing a real opportunity to stay ahead of the game in this technology, and it would be foolish for us to adhere to a rigid ideology about—using that ideology to not make a good judgment here, to be involved in this next stage of research. Mr. Chairman, I yield back.

Chairman WEBER. I thank the gentleman from California. It's time for our friend from Colorado, Mr. Perlmutter.

Mr. PERLMUTTER. Thanks, Mr. Chairman, and thank you to the panel. I've been around long enough to know that early stage and late stage and basic and applied from, you know, Congress to Congress, from administration to administration, we kind of whipsaw the Department of Energy, saying, okay. We like early stage. We like late stage. But sometimes late stage becomes early stage, and I'd like to run a clip from a TV report from yesterday about the National Renewable Energy Lab.

[Video shown.]

So really, you know, pretty inspiring. And I just, again, obviously I'm very proud of the National Renewable Energy Lab. I'm proud of the Department of Energy just because you have a lot of very bright people there.

So Dr. Keller, if you'd like to comment on that for a second? And then after that, I have some questions for my brothers in the bar.

Dr. KELLER. Thank you very much. Look, this was a video to show you how science is done. So if you have smart people and creative people and they have an experiment that went wrong, and they say, oh. What about this? And they change and adapt. And this is something which makes the National Lab System, DOE but also the scientist. This is the strength of the United States. I think that we have the best and most brilliant people doing this. I mean, I compare this again through my traveling where we have the edge. If you compare us, our science, to other countries, we are still much more creative. We live in a system which enables creativity, and I think this is why it's so important to continue to support researchers through federal funds.

Mr. PERLMUTTER. Okay. And I thank you for that. And so, you know, Mr. Simmons, I was encouraged by some of your comments concerning the National Renewable Energy Lab, and really, you know, whether it's basic science or applied science, I mean, depends, you know, what you want to call it. but it's sort of on this continuum.

But one of the things I am concerned about—and so I'm going to ask some math questions of my attorney friends. You know, at 207 million, that's the solar budget from last year for '17. It's going to get cut to 70 million, okay? So let's go with the higher number, the 207 million. We are in the throes of dealing with a tax cut that's going to cost the country about $1.5 trillion, at best. Do you have any idea how many solar energy budgets fit into $1.5 trillion? And I'll give you like two or three seconds, not embarrass you, because we've got the scientists here. But I've done the math, so I'll help you.

Mr. SIMMONS. Well, there was a reason I went to law school.

Mr. PERLMUTTER. Okay. Mr. Stein?

Mr. STEIN. I'm not going to do the math in my head. It's——

Mr. PERLMUTTER. All right. So—and I don't want to make—you know, I went to law school——

Mr. STEIN. You're good with—

Mr. PERLMUTTER. —and I'm proud of being a lawyer and I'm proud you guys are lawyers. But the answer is 7,142.85 budgets for solar energy. Let's round it up to 7,143. Let's take all of the EERE budget for '17 which is $2.90 billion, reduced to $636 million. At 2 billion, let's round it down just to make the numbers easy. That's 750. And so I appreciate, gentlemen, you know, some of the questions about, you know, spending too much and cost overruns. But everything is relative and in perspective. These laboratories—and Mr. Simmons, you are now, you know, not burdened but you are tasked with really working with them and getting the best out them because they do bring good things to light. And these cuts that we're going to face are really, you know, just—they are paralyzing. And so I appreciate this panel being here. I appreciate some of the, you know, the comments of our engineers and scientists as well as the kind of the focus that you gentlemen have, you know, as to what should the government be doing, you know? What is our role? But we do know that we are making some substantial steps. And I don't want to see us to step backwards from that. This country is too good for that. With that, I yield back to the chair.

Chairman WEBER. I thank the gentleman. I thank the witnesses for their valuable testimony and the Members for their questions.

The record will remain open for two weeks for additional comments and written questions from the Members. This hearing is adjourned.

[Whereupon, at 3:36 p.m., the Subcommittee was adjourned.]

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