INNOVATIONS IN BATTERY STORAGE FOR RENEWABLE ENERGY

HEARING

BEFORE THE

SUBCOMMITTEE ON ENERGY

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED FOURTEENTH CONGRESS

FIRST SESSION

MAY 1, 2015

Serial No. 114–18

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

95–223PDF WASHINGTON : 2015

For sale by the Superintendent of Documents, U.S. Government Publishing Office
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CONTENTS

May 1, 2015

INNOVATIONS IN BATTERY STORAGE FOR RENEWABLE ENERGY

FRIDAY, MAY 1, 2015

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

The Subcommittee met, pursuant to call, at 9:10 a.m., in Room 2318 of the Rayburn House Office Building, Hon. Randy Weber [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas
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Congress of the United States
House of Representatives

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Subcommittee on Energy

Innovations in Battery Storage for Renewable Energy

Friday, May 1, 2015
9:00 a.m. – 11:00 a.m.
2318 Rayburn House Office Building

Witnesses

Dr. Imre Gyuk, Energy Storage Program Manager, Office of Electricity Delivery and Energy Reliability, Department of Energy

Dr. Jud Virden, Jr., Associate Laboratory Director for Energy and Environment Directorate, Pacific Northwest National Laboratory

Mr. Phil Giudice, Chief Executive Officer, Ambri

Dr. Jay Whitacre, Chief Technology Officer, Aquion Energy

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

HEARING CHARTER

Innovations in Battery Storage for Renewable Energy

Friday, May 1, 2015
9:00 a.m. – 11:00 a.m.
2318 Rayburn House Office Building

PURPOSE

The Subcommittee on Energy will hold a hearing titled *Innovations in Battery Storage for Renewable Energy* on Friday, May 1, 2015, starting at 9:00 a.m. in Room 2318 of the Rayburn House Office Building. The purpose of the hearing is to provide an overview of the state of large-scale battery storage and recent technology breakthroughs achieved through research and development at the Department of Energy national laboratories. The hearing will also highlight how innovative companies are transitioning basic science research in battery storage technology conducted at the national laboratories to the commercial market.

WITNESS LIST

- **Dr. Imre Gyuk,** *Energy Storage Program Manager, Office of Electricity Delivery and Energy Reliability*, Department of Energy
- **Dr. Jud Virden, Jr.,** *Associate Laboratory Director for Energy and Environment Directorate*, Pacific Northwest National Laboratory
- **Mr. Phil Giudice**, *Chief Executive Officer*, Ambri
- **Dr. Jay Whitacre**, *Chief Technology Officer*, Aquion Energy

BACKGROUND

Because power production from renewable energy sources like wind and solar is intermittent and dependent on weather, utilities struggle to predict when renewable power will be available. Adding renewable sources to the power grid also increases the complexity and challenge of operating an electricity system to match supply and demand.[1]

Large-scale energy storage through batteries is a critical component of successfully integrating renewable resources like wind and solar into the power grid. This allows utilities to use power produced from renewable energy when and where it is necessary, taking full advantage of available renewable energy sources. Common forms of energy storage typically include methods that convert electricity to kinetic or potential energy, through pumped

[1] Pacific Northwest National Laboratory, *Large-scale energy storage*, Available at http://energyenvironment.pnnl.gov/ei/energy_storage.asp

hydroelectric and compressed air systems, and then discharge that energy back to the grid when demand is high.[2]

Through the development of advanced battery technology, electricity could be efficiently stored in electrochemical energy storage systems and then released when needed, without being dependent on natural resources like hydroelectric storage. Diverse battery technology could address two key energy storage needs: providing high power applications where the battery must respond rapidly and be able to discharge electricity for short time periods, or providing energy management applications where the battery may respond more slowly, but must be able to discharge electricity for several hours.[3] Grid-scale energy storage technology typically involves different chemical reactions and battery construction. Two different battery designs are redox flow and solid-state. Redox flow batteries typically contain slow chemical processes well-suited for energy management, while solid state batteries contain potential for high energy density and rapid energy discharge.[4]

The Department of Energy Office of Electricity Delivery and Energy Reliability's (OE) Energy Storage Program conducts research and development on a broad variety of energy storage mechanisms, including conventional and advanced batteries, flywheels, electrochemical capacitors, superconducting magnetic energy storage (SMES), power electronics, and control systems, as well as research and development into advanced electrolytes and nano-structured electrodes to improve energy storage density.[5] According to DOE, enhanced energy storage can provide benefits to the power industry and consumers, to include improved power quality, improved stability and reliability of transmission and distribution systems, improved availability of distributed generation sources, and increasing the lifespan of existing infrastructure and electricity equipment. Challenges to widespread deployment of energy storage technologies include cost, validated reliability and safety, regulatory challenges, and industry acceptance.[6]

Important questions and key issues to be discussed at the hearing include:

- What are the Administration's goals for energy storage technology research and development?
- What are key technology breakthroughs achieved through the Department of Energy's work on grid-scale energy storage? How have those breakthroughs transferred to the private sector?

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[2] Pacific Northwest National Laboratory, *Large-scale energy storage,* Available at http://energyenvironment.pnnl.gov/ei/energy_storage.asp
[3] Congressional Research Service, *Energy Storage for Power Grids and Electric Transportation: A Technology Assessment*, March 27, 2012. Available at http://www.fas.org/sgp/crs/misc/R42455.pdf
[4] Pacific Northwest National Laboratory, *Large-scale energy storage,* Available at http://energyenvironment.pnnl.gov/ei/energy_storage.asp
[5] Department of Energy, Office of Electricity Delivery and Energy Reliability, *Energy Storage Program*, Available at http://energy.gov/oe/services/technology-development/energy-storage
[6] Department of Energy, *Grid Energy Storage*, December 2013. Available at http://energy.gov/sites/prod/files/2014/09/f18/Grid%20Energy%20Storage%20December%202013.pdf

- What basic research has contributed to the development of private sector witnesses' unique battery technology? In what ways did partnership with the national labs and the Department of Energy advance the development of private sector battery technology?

- What next steps in R&D and technology development will contribute to expanded use of advanced, grid-scale energy storage technology by the private sector? What impact could the deployment of new battery storage technologies by the private sector have on the energy market, particularly for reducing cost and increasing reliability for renewable power?

Additional Reading:

Bloomberg Business, *The $5 Billion Race to Build a Better Battery*, Available at http://www.bloomberg.com/news/articles/2015-04-14/gates-pritzkers-take-on-musk-in-5-billion-race-for-new-battery

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 which we might go ahead and do. Have you all eaten breakfast? So I want to thank you all for being here today.

Today's hearing is titled Innovations in Battery Storage for Renewable Energy.

I recognize myself for five minutes for an opening statement.

Today, we will hear from government and industry witnesses on the state of large-scale battery storage, and recent technology breakthroughs achieved through research and development at the national labs and universities around the country. Our witnesses today will also provide insight into how innovative companies are transitioning basic science research in battery storage technology to the energy marketplace.

Energy storage could revolutionize electricity generation and delivery in America. Cost-effective, large-scale batteries could change the way we power our homes, reduce infrastructure improvement costs, and allow renewable energy to add power to the electric grid without compromising reliability or increasing consumer costs. As a Texan, trust me, I know the value of reliable, affordable energy. With a population in Texas that is increasing by 1,000 people a day, or more, and energy-intensive industries driving consumption, Texas is by far the nation's largest consumer of electricity. The Texas economy needs reliable and affordable energy to power long-term growth, plain and simple. With battery storage technology, Texas could count on power from conventional and renewable energy sources regardless of the weather, saving money for Texas consumers and keeping the Texas power grid reliable and secure.

Although large-scale battery storage has been available for decades, there is still more work to be done. Fundamental research and development into the atomic and molecular structure of batteries is needed to better understand the operation, performance limitations, and the failures of battery technology. At our national labs, we have the facilities and expertise necessary to conduct this basic research. The private sector plays an instrumental role in commercializing next generation battery technology. Through partnerships with the national labs, innovative battery companies can take advantage of cutting-edge research and user facilities, and develop cost-effective, efficient energy storage technology that can compete in today's energy marketplace. Instead of duplicating deployment efforts that can be done by the private sector, the federal government should prioritize basic research and development on energy storage. This investment in energy storage technology R&D can benefit all forms of energy while maintaining that reliability and the security of the nation's electric grid.

Current U.S. policy for advancing the deployment of renewable energy is built around federal subsidies and tax credits. But these policies only tend to increase costs for the American people, and are counterproductive to the development of battery storage technology that could make renewable power a good investment in the real world. By creating an incentive to invest in renewable energy deployment instead of energy storage, the federal government is actually steering investment away from battery storage technology.

And the truth is, without affordable and efficient energy storage, renewable energy will never be able to match the efficiency, affordability, and reliability of fossil fuels. Instead, the federal government should end market-distorting subsidies and tax credits for the renewable energy industry, and allocate those resources to basic research and development necessary to solve the challenge of energy storage.

I want to thank our witnesses for testifying to the Committee today, and I look forward to a discussion about federal energy storage research and development, and the impact efficient and affordable batteries can have on energy reliability and security.

I now recognize the Ranking Member, the gentleman from Florida, for an opening statement.

[The prepared statement of Chairman Weber follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON ENERGY
CHAIRMAN RANDY K. WEBER

Good morning and welcome to today's Energy Subcommittee hearing examining innovations in battery storage technology. Today, we will hear from government and industry witnesses on the state of large-scale battery storage, and recent technology breakthroughs achieved through research and development at the national labs and universities around the country. Our witnesses today will also provide insight into how innovative companies are transitioning basic science research in battery storage technology to the energy marketplace.

Energy storage could revolutionize electricity generation and delivery in America. Cost effective, largescale batteries could change the way we power our homes, reduce infrastructure improvement costs, and allow renewable energy to add power to the electric grid without compromising reliability or increasing consumer costs.

As a Texan, I know the value of reliable, affordable energy. With a population that is increasing by more than 1,000 people per day, and energy intensive industries driving consumption, Texas is by far the nation's largest consumer of electricity. The Texas economy needs reliable and affordable energy to power long-term growth. With battery storage technology, Texas could count on power from conventional and renewable energy sources regardless of the weather, saving money for Texas consumers and keeping the Texas power grid reliable and secure. Although large-scale battery storage has been available for decades, there is still more work to be done.

Fundamental research and development into the atomic and molecular structure of batteries is needed to better understand the operation, performance limitations, and failures of battery technology. At our national labs, we have the facilities and expertise necessary to conduct this basic research.

The private sector plays an instrumental role in commercializing next generation battery technology. Through partnerships with the national labs, innovative battery companies can take advantage of cutting edge research and user facilities, and develop cost-effective, efficient energy storage technology that can compete in today's energy marketplace. Instead of duplicating deployment efforts that can be done by the private sector, the federal government should prioritize basic research and development on energy storage. This investment in energy storage technology R&D can benefit all forms of energy while maintaining reliability and the security of the nation's electric grid.

Current U.S. policy for advancing the deployment of renewable energy is built around federal subsidies and tax credits. But these policies tend to increase costs for the American people, and are counterproductive to the development of battery storage technology that could make renewable power a good investment in the real world. By creating an incentive to invest in renewable energy deployment instead of energy storage, the federal government is steering investment away from battery storage technology. And the truth is, without affordable and efficient energy storage, renewable energy will never be able to match the efficiency, affordability, and reliability of fossil fuels.

Instead, the federal government should end market-distorting subsidies and tax credits for the renewable energy industry, and allocate resources to basic research and development necessary to solve the challenge of energy storage.

I want to thank our witnesses for testifying to the Committee today, and I look forward to a discussion about federal energy storage research and development, and the impact efficient and affordable batteries can have on energy reliability and security.

Mr. GRAYSON. Thank you, Chairman Weber, for holding this hearing. And thank you to our witnesses this morning for participating.

Today we'll be discussing energy storage and the potential benefits that can be gained by developing storage technologies. Energy storage has the potential to solve problems such as interruptions in power on the electric grid, we all know how frustrating and, at times, even dangerous a power outage can be, and to make intermittent renewable sources of energy more practical and affordable.

Energy storage allows the buying of energy when prices are low, and the selling of energy when prices are high. This capability can lead to a reduction in energy congestion on America's electrical infrastructure; lowering prices for consumers, and also potentially lowering utility revenues for providers. We have to plan that out accordingly. Well-placed storage units can eliminate the need for building additional transmission lines in some areas, saving consumers money. These challenges to existing energy infrastructure business models will grow as residential storage systems become more affordable.

Japan, according to Bloomberg Business, is said to spend $670 million in response to the grid issues that it's facing, so that it'll be able to accommodate the influx of renewable energy, which is often intermittently produced. In contrast, our Department of Energy's Office of Electricity Storage Program was funded at only $12 million; that's $670 million versus $12 million, for Fiscal Year 2015. We need to do better than this if we want to maintain a reliable, resilient electric grid that can accommodate the many new forms of energy production and storage that are emerging today. Lawrence Berkeley National Lab estimated the annual costs associated with interruptions in power are as high as $135 billion, and often it's the commercial and industrial sectors in our economy that bear those costs. In a future in which manufacturing processes increasingly rely on digital technology, even short, brief outages can dramatically impact production and sales.

Energy storage solutions provide a line of defense against the cost of an outage, and it is imperative that America be prepared to incorporate storage solutions into energy and electrical infrastructure. If we invest wisely, research programs in electrical and energy storage can help America move from our current 20th century energy grid to a future grid that delivers more and pollutes less.

And federally funded research has the potential to create new product lines, new business opportunities, and new international markets. Storage technology can make America's energy future arrive faster, and that's always our goal; to make the future arrive faster.

Again, I thank each of our witnesses for being here today, and I look forward to hearing what each of you has to say.

Thank you, Mr. Chairman. I yield back my time.

[The prepared statement of Mr. Grayson follows:]

PREPARED STATEMENT OF SUBCOMMITTEE ON ENERGY
MINORITY RANKING MEMBER ALAN GRAYSON

Thank you, Chairman Weber, for holding this hearing, and thank you to our witnesses for appearing here today.

Most of us take the electric grid for granted. We flip a switch and the lights come on. But all of us have experienced outages.

Lawrence Berkeley National Lab estimated that the annual costs associated with interruptions in power are between $22 billion and $135 billion, most of which is borne by the commercial and industrial sectors.

As we move to manufacturing and industrial processes that rely more and more on digital technology to operate, even short outages can impact the cost of doing business. According to the Lab's study, two thirds of industrial and commercial outage costs were due to outages lasting less than five minutes. These outages alone translate to a $52 billion dollar price tag.

Storage can solve this problem.

We will hear today about many of the other benefits storage can provide.

Even with these benefits, however, storage technologies may face opposition because storage is a technology that can permanently disrupt the electricity sector's business-as-usual model.

Storage allows you to buy energy when prices are low, and sell it when prices are higher. Likewise storage can be used to reduce electricity congestion, lowering prices in high market areas, which benefits consumers but lowers utility revenues.

Well placed storage units can eliminate the need for building additional transmission lines, saving consumers money. But this can also decrease utility revenues tied to rate increases for capital expenditures.

These challenges to the existing industry business model are the beginning. There's more to come. If residential storage systems become affordable, business models will need to adapt again.

It should be noted that, despite the title of this hearing, storage isn't really needed to maintain grid reliability when using renewable energy until you get to very high penetration levels of around 30 percent or more, according to the American Wind Energy Association. For now, there are actually many other mechanisms to address the variability of these resources that are more cost-effective. So a lack of storage is not an immediate show-stopper for renewables. But at some point, we may well want to go higher than 30%, and affordable large-scale storage technologies could become an even bigger game-changer for our environment as well as our energy security.

Energy storage is a powerful enabling technology that can benefit all of us. It can improve the resiliency and efficiency of our electrical infrastructure.

If we invest wisely, research programs in storage technologies can help us transition from our current grid to a future grid with lower carbon emissions. And, at the same time, federal research can open up new business opportunities, new product lines, and new international markets.

Earlier this year, Bloomberg News reported that the Japanese Ministry of Economy, Trade, and Industry (METI) may be investing more than $400 million in grid-scale energy storage technologies. In contrast, the DOE's Office of Electricity Storage Program FY 2015 budget was $12 million. The budget request for FY 2016 is $21 million. We can do better than this.

Storage can be the next revolution in our energy future if we invest sensibly. We should be doing everything we can to make this future come faster.

Thank you and I yield back.

Chairman WEBER. Thank you, Mr. Grayson. And I now recognize the Chairman of the Full Committee, Mr. Smith.

Chairman SMITH. Thank you, Mr. Chairman. I thought I'd mention to members at least part of the reason and part of the genesis for this hearing today. A couple of years ago, I was meeting in my office with the author of a Pulitzer Prize-winning book on energy. His name is Daniel Yergin, and I suspect many of you have heard of him. He also happens to have been a college classmate. And I asked him what was the single most important thing we could do to help consumers with energy, and he replied, develop a better battery, or develop a battery that had better storage capability. And even though that conversation took place a couple of years ago, that really led to today's hearing. And so that's how important I think it is, and how important at least one other expert thinks the development of better battery storage is as well.

Mr. Chairman, today the Subcommittee on Energy will examine breakthrough technology in battery storage for renewable energy. Battery storage is the next frontier in energy research and development. Advanced batteries will help bring affordable renewable energy to the market without costly subsidies or renewable energy mandates. Forty-five percent of new U.S. power production last year came from wind turbines, while solar power made up 34 percent of new global power capacity. But without the capacity to efficiently store the energy produced when the sun isn't shining and the wind isn't blowing, renewable energy makes a minimal contribution to America's electricity needs. Advanced battery technology will enable utilities to store and deliver power produced by renewable energy. This will allow us to take advantage of energy from the diverse natural resources available across the country.

My home State of Texas offers a ready example of the impact battery storage could have on harnessing renewable power. Texas is the top wind producing state in the country. The Lone Star State currently operates more than 12,000 megawatts of utility-scale wind capacity; about 1/5 of the total wind capacity in the United States. In ideal circumstances, wind generates up to 18 percent of Texas' power. But even with this significant capacity, Texas wind energy cannot produce power on demand. And when energy needs are the highest, wind makes up just three percent of Texas power generation. Advanced battery technology could help the United States meet its energy needs and effectively manage its power production when conventional and renewable energy resources, which will save money for energy consumers. Federal research and development can build the foundation for the next breakthrough in battery technology.

Mr. Chairman, I know votes have been cast, so if—I'd like to ask unanimous consent that the rest of my opening statement be made a part of the record so that we can at least get our witnesses introduced before we need to leave for votes, and then I know Members will return after that.

I will yield back.

Chairman WEBER. Without objection. Thank you.

[The prepared statement of Chairman Smith follows:]

PREPARED STATEMENT OF CHAIRMAN LAMAR S. SMITH

PREPARED STATEMENT OF FULL COMMITTEE CHAIRMAN LAMAR S. SMITH

Good morning. Today, the Subcommittee on Energy will examine breakthrough technology in battery storage for renewable energy.

Battery storage is the next frontier in energy research and development. Advanced batteries will help bring affordable renewable energy to the market without costly subsidies or renewable energy mandates. Forty-five percent of new U.S. power production last year came from wind turbines, while solar power made up 34 percent of new global power capacity.

But without the capacity to efficiently store the energy produced when the sun isn't shining and the wind isn't blowing, renewable energy makes a minimal contribution to America's electricity needs. Advanced battery technology will enable utilities to store and deliver power produced by renewable energy. This will allow us to take advantage of energy from the diverse natural resources available across the country.

My home state of Texas offers a ready example of the impact battery storage could have on harnessing renewable power. Texas is the top wind producing state in the country. The Lone Star State currently operates more than 12,000 megawatts of utility-scale wind capacity—about one-fifth of the total wind capacity in the United States. In ideal circumstances, wind generates up to 18 percent of Texas' power.

But even with this significant capacity, Texas wind energy cannot produce power on demand. And when energy needs are the highest, wind makes up just 3 percent of Texas power generation. Advanced battery technology could help the U.S. meet its energy needs and effectively manage its power production from conventional and renewable energy resources, which will save money for energy consumers.

Federal research and development can build the foundation for the next breakthrough in battery technology. At the Pacific Northwest National Lab (PNNL), home to one of today's witnesses, researchers are developing new approaches for large-scale energy storage. PNNL conducts research on battery technologies, including innovative battery electrodes to improve energy storage capacity.

Using the powerful transmission electron microscope at the Environmental Molecular Sciences Laboratory, scientists can study damage caused by battery recharging.

This basic research on the fundamental challenges to safe, efficient, and affordable battery technology has incredible value and application for the private sector. It will help the private sector lead the way to bring battery storage technology to the energy marketplace.

Inspired by the fundamental research conducted at the Department of Energy national labs and universities around the country, the private sector is now investing in battery storage technology. American entrepreneurs have invested over $5 billion in battery research and development over the last decade, which has helped fuel a renaissance in new battery technology.

Just this week, the tech company Tesla announced it will expand into the battery market, manufacturing home batteries to help consumers cut costs and to provide back-up power to their homes. And Tesla's potential large-scale utility batteries can be used for renewable power generation.

Two of our witnesses today represent innovative energy storage companies, with unique battery designs developed through basic research. I look forward to hearing more about the impact these new concepts for battery chemistry and construction can have on our economy and renewable energy production.

While the private sector funding will deploy next generation battery technology into the energy marketplace, the federal government should invest in basic research and development that can revolutionize battery technology.

Prioritizing the ongoing partnership between the national labs and American entrepreneurs can develop next generation battery technologies and keep America at the forefront of battery science.

Thank you Mr. Chairman and I yield back.

Chairman WEBER. Let me introduce our witnesses. Our first witness today is Dr. Imre Gyuk. Okay, good German name. The Energy Storage Program Manager for the Department of Energy's Office of Electricity Delivery and Energy Reliability. His work involves research on a wide variety of technologies, including advanced batteries, flywheels, the super-capacitors, and compressed air energy storage. Dr. Gyuk received his Bachelor's Degree from Fordham University, and his Ph.D. in theoretical physics from Purdue University.

Our next witness is Dr. Virden, Associate Laboratory Director for the Energy and Environment Directorate at Pacific Northwest National Laboratory. Now, that's a mouthful. At PNNL, Dr. Virden leads a team of 1,000 staff in delivering science and technology solutions for energy and environmental challenges. And he's been with the lab for over two decades. Dr. Virden holds two United States patents, and has received R&D 100 and Federal Laboratory Consortium awards for non-thermal plasma technology, a Discover Award from MIT for fuel reformation technologies, and he contributed to a Financial Times Global Automotive Award for PNNL's assistant to Delphi's non-thermal plasma technology for automotive applications. Dr. Virden earned his Bachelor's Degree and Ph.D. in chemical engineering from the University of Washington. Welcome.

Mr. Giudice—actually, I'm going to yield to the gentlewoman from Massachusetts, because I think she knows something about him, to introduce him.

Ms. CLARK. Thank you, Mr. Chairman.

It is my pleasure to introduce Mr. Phil Giudice, the CEO of Ambri, and a constituent of mine from Wayland, Massachusetts. Ambri is a technology company in Massachusetts that is creating cost-effective and reliable battery technology that has the potential to revolutionize the grid. Phil, in addition to leading Ambri, has more than 30 years of experience throughout the energy industry. He has worked as a geologist, a consultant, a manager, and a public servant. I will highlight just a few of his many, many accomplishments on his resume. Phil is a Board Member for FirstFuel, an efficiency startup; Advanced Energy Economy, an energy business leadership trade group; and the New England Clean Energy Council. He was an appointee to the Department of Energy's Energy Efficiency and Renewables Advisory Committee, as well as its State Energy Advisory Board. And he has served the Commonwealth as Undersecretary of Energy, and Commissioner of the State's Department of Energy Resources. I want to thank you, Phil, and the entire panel for joining us today, and we look forward to your testimony.

I yield back.

Chairman WEBER. I thank the gentlewoman from Massachusetts.

Our final witness today is Dr. Jay Whitacre, Founder and Chief Technology Officer for Aquion Energy. Dr. Whitacre became an Assistant Professor at Carnegie Mellon in 2007, with a joint appointment in material science and engineering, and engineering in public policy departments, where he developed the chemistry that is the basis for Aquion Energy's product line. Dr. Whitacre received his Bachelor's Degree in physics from Oberlin College, and received his Master's and Ph.D. in material science and engineering from the University of Michigan.

That concludes the introduction of the witnesses, and unfortunately, as The Chairman said, they have called votes, so we are going to recess and then we will reconvene immediately after the last vote on the Floor.

The Subcommittee stands in recess.

[Recess.]

Chairman WEBER. We're going to reconvene this hearing, and we're going to recognize our first witness, Dr. Gyuk.

TESTIMONY OF DR. IMRE GYUK, ENERGY STORAGE PROGRAM MANAGER, OFFICE OF ELECTRICITY DELIVERY AND ENERGY RELIABILITY, DEPARTMENT OF ENERGY

Dr. GYUK. Chairman Smith, Chairman Weber, Ranking Member Grayson, and Members of the Committee, thank you for your invitation to testify at today's hearing. I appreciate the opportunity to tell you about the energy storage program of DOE's Office of Electricity Delivery and Energy Reliability, and the serious efforts the program is making to address the challenges facing the widespread deployment of grid energy storage.

I am pleased to be part of this panel with some of my distinguished colleagues who have been great partners over the years.

Last week, the Administration released the first ever quadrennial energy review. The QER takes a broad look at the infrastructure used for the transmission storage and distribution of energy. Several of the QER findings and recommendations addressed the opportunities that grid energy storage can provide to modernize the electric grid.

Today, I would like to highlight our work over the last dozen years to develop energy storage technology, working on materials and devices, and to bring them into commercialization.

The program is firmly based on the knowledge and expertise of the National Laboratories. We work with Sandia, Pacific Northwest Laboratory and Oak Ridge in a fully integrated program which produces cutting-edge research focused on commercialization. And this focus on commercialization is essential. We also involve universities and industry as appropriate. We pursue a wide portfolio of technologies for a broad spectrum of applications. Some of the technologies we have studied include advanced lead carbon batteries, sodium ion systems, magnesium ion systems, and flow batteries involving vanadium, zinc iodide and organo-metallics. We bring promising chemistries all the way from basic investigations through device development, and into licensing and deployment.

I would like to share some success stories in deploying energy storage technologies, and then discuss how OE's program is addressing the major challenges.

At Notrees, a small town near Odessa in west Texas, we partnered with Duke Energy to build a 36 megawatt facility for wind smoothing and frequency regulation. The installation helped to inform the Texas Public Utility Commission on developing rules for ancillary services. Tehachapi, California, is the site of the world's largest wind field. But sometimes the wind blows and sometimes it doesn't, and so we partnered with Southern California Edison to build an eight megawatt, four hour lithium ion facility to mitigate the variable nature of the wind.

I believe strongly that federal programs need to work directly with the States, making the expertise developed by the national laboratories available to the public. For example, in Vermont, we are partnering with the Public Service Department to build a disaster-resilient micro-grid, combining four megawatts of storage with two megawatts of photovoltaics. During emergencies, the facility can function as a community shelter and maintain critical services indefinitely, even without input from the surrounding grid, which may well be down. In Detroit, we are exploring a community energy storage concept, incorporating reused electrical vehicle batteries. In Washington State, we are leveraging state funds to commercialize a battery technology that started with research at PNNL. Avista just inaugurated a one megawatt, three hour flow battery based on vanadium a few weeks ago, and two megawatts with Snohomish will soon follow. We will evaluate the operation of the facility, and make careful cost benefit evaluations.

DOE has developed a strategic energy storage plan which identifies four priorities, which form the framework for the OE Storage Program. One is lowering costs. That comes first. Two is validating reliability and safety. Three is helping to develop an equitable regulatory environment for storage. And four is furthering industry acceptance. The program has provided key leadership in establishing energy storage as an effective tool for promoting grid reliability, resilience, and better asset utilization of renewable Energy.

Although grid energy storage has made a credible beginning, much remains to be done. DOE looks forward to continuing this important work. As our electric grid evolves, we expect that energy storage will be an integral component in assuring that electricity delivery for communities, business, and industry will be more flexible, secure, reliable, and environmentally responsive.

Mr. Chairman, and members of the Committee, this completes my prepared statement. I will be happy to answer any questions you may have.

[The prepared statement of Dr. Gyuk follows:]

Statement of Dr. Imre Gyuk, Program Manager for Energy Storage Research
Office of Electricity Delivery and Energy Reliability
U.S. Department of Energy
Before the
Committee on Science, Space and Technology
Subcommittee on Energy
U.S. House of Representatives
May 1, 2015

Chairman Weber, Ranking Member Grayson, and members of the Committee, thank you for your invitation to testify at today's hearing on "Innovations in Battery Storage for Renewable Energy." I appreciate the opportunity to share with you the important progress the Department of Energy's Office of Electricity Delivery and Energy Reliability (OE) Energy Storage Program is making to address the challenges facing the widespread deployment of grid energy storage.

Electricity is central to the well-being of the Nation. The United States has one of the world's most reliable, affordable, and increasingly clean electric systems, but it is currently at a strategic inflection point—a time of significant change for a system that has had relatively stable rules of the road for nearly a century. Last week, the Administration released the first-ever Quadrennial Energy Review (QER). This first installment of the QER looks at the infrastructure used for the transmission, storage, and distribution of energy. Included is a major look at the electricity part of that infrastructure, in terms of modernizing the electric grid. Several of the QER's findings and recommendations note and address the opportunities that grid energy storage can provide as part of its role in modernizing the electric grid.

As the QER points out, changes in technologies, markets, and public policies are transforming electricity delivery. Some key trends driving the evolution of the grid include a changing mix of electricity generation sources and characteristics, growing expectations for a resilient and responsive power grid, and growing customer participation in retail electricity markets. Much innovation is occurring in electricity technologies, including innovation in grid energy storage as this panel will hear today. Today, I will discuss the Department of Energy's role in grid storage innovation.

Grid Energy Storage Defined

Grid energy storage helps address, among other existing and emerging methods, the continuous 24/7 need to balance the generation of electricity and demand for electricity from the grid's customers. That balance must be maintained on a narrow and precise basis and must address a set of legally-enforceable reliability standards set by Congress in its Energy Policy Act of 2005.

Storage provides a buffer between generation and customer demand, freeing the grid from the need for instantaneous response. Energy storage increases reliability and resiliency of the electric grid and can provide greater asset utilization of generation. Energy storage provides power when it is needed, just as transmission and distribution provide power where it is needed.

The OE Program

The Department of Energy's Office of Electricity Delivery and Energy Reliability's mission is to drive electric grid modernization and resiliency in energy infrastructure. OE accomplishes this mission through research, partnerships, facilitation, modeling and analytics, and emergency preparedness. OE's Energy Storage Program is an important component of the Department's strategy to support a more economically competitive, environmentally responsible, secure and resilient U.S. energy infrastructure by accelerating the development of emerging storage technologies.

The program's R&D activities focus on lowering cost while improving value, and advancing the performance, safety, and reliability of stationary energy storage technologies for utility-scale applications. Additionally, the program is designed to work with states, communities, industry, and other stakeholders to develop and demonstrate energy storage technologies, devices, and systems that can reduce power disturbances, improve system flexibility to better incorporate growing use of variable renewable resources, reduce peak demand, and provide resiliency to advance the modernization of the electrical utility grid.

The OE Energy Storage Program is an integrated program: it takes technologies from applied electrochemistry through device and system development, to field tests and applications. The focus is firmly on commercialization and transfer to the private sector. The program involves National Laboratories working closely together as well as projects at universities, private industry, and initiatives through the Small Business Innovation Research (SBIR) program. The program has an annual public peer review and reports its result in numerous public forums. In collaboration with the Advanced Research Projects Agency-Energy (ARPA-E), the Office of Science, and the Office of Energy Efficiency and Renewable Energy (EERE), OE has developed a

Grid Energy Storage report[a] that forms the framework of the storage program and identifies the following priorities:

- Cost competitive energy storage technologies: targeted scientific investigations of key materials and systems
- Validated reliability & safety: independent testing of prototypic devices and understanding of degradation.
- Equitable regulatory environment: enabling industry, utility, and developer collaborations to quantify benefits and provide input to regulators.
- Industry acceptance: highly leveraged field demonstrations and development of storage system design tools.

Collaboration within the Department

To further leverage work done by various DOE offices on this issue, DOE has developed a crosscutting effort involving the OE, the Office of Energy Efficiency and Renewable Energy, and the Office of Energy Policy and Systems Analysis called the Grid Modernization Initiative.

EERE is working on energy storage across several offices including solar, vehicles, fuel cells, and wind and water power. Much of the work is focused on vehicles and behind-the-meter storage. EERE is also involved in pumped storage hydro and thermal energy storage combined with concentrating solar power.

In addition, OE activities are complemented by efforts from ARPA-E and the Office of Science. For example, ARPA-E has efforts in grid storage, such as the "Grid-Scale Rampable Intermittent Dispatchable Storage" (GRIDS) and "Agile Delivery of Electrical Power Technology" (ADEPT) programs. DOE's Office of Science, through its Basic Energy Sciences program, supports a portfolio of fundamental research to provide scientific understanding of the physical and chemical phenomena underpinning the properties of batteries, fuel cells, and supercapacitors, including the Joint Center for Energy Storage Research. The Grid Energy Storage report further describes the roles each office plays in the energy storage field.

[a]http://energy.gov/oe/downloads/grid-energy-storage-december-2013

Developing Technology for Commercialization

Although the notion of practical widespread energy storage appears evident, it was almost an unknown concept in the utility world some 12 years ago. The exception is pumped hydro, of which 22 GW of installed capacity currently exists in the United States.

Since 2003, DOE OE has been in the forefront of developing energy storage into a technology ready for commercialization by industry. This has meant taking the field from research to development, to demonstrations in niche markets, until it is finally ready to enter the mass market. The program has informed regulatory changes, policy adoption, and sizable investments. Progress is remarkable, but there is more work to be done to develop technologies that could allow widespread deployment of energy storage technologies by industry.

Recent Successful Projects

The American Recovery and Reinvestment Act of 2009 (ARRA) provided a very considerable boost to the development of the program. OE received $185 million of funding for storage demonstration projects, but was able to boost this with $585 million of cost share from industry. This showed evidence of strong buy-in from industry and utilities.

Selected through a competitive solicitation, 16 projects were chosen for funding. The scope comprised a spectrum from large utilities, to small companies, and recent start-ups. The technologies involved were diverse, including advanced batteries, flow batteries, flywheels, and compressed air.

The goal of the projects was fourfold: to show technical feasibility, gather cost data, inform regulatory changes, and generate follow-on projects. Most of the projects were first of a kind and established technological know-how and business cases that provided the basis for later development. I highlight examples of successful projects throughout the testimony.

Power Systems and Energy Systems

Energy storage systems provide for multiple applications in the electric system: energy management, backup power, load leveling, frequency regulation, voltage support, and grid stabilization. However, not all storage systems are equal because not every type of storage is suitable for every type of application, motivating the need for a portfolio strategy for energy storage technology. Therefore, the OE program develops a broad portfolio of technologies for a wide spectrum of applications. Storage applications can involve power systems or energy systems.

Power systems for storage respond rapidly, but their energy content is limited. They are appropriate for smoothing out the short term variability of wind and solar renewable generation, as one of several methods that can be used to address that variability. They can also provide "frequency regulation" that is used by grid operators to maintain grid stability and thus reliability. A 20MW flywheel project developed with OE funding demonstrated that frequency regulation provided by storage can be twice as technically effective as doing the same thing by generation that currently provides such frequency regulation. In Texas, OE also supplied funding for an advanced lead-acid battery facility. Built by Duke Energy in Notrees, West Texas, the impressive 36MW battery provides wind smoothing and frequency regulation services to the grid. This project helped inform the Texas Public Utility Commission's new regulations regarding storage. Since the completion of these two projects, the Federal Energy Regulatory Commission issued in 2013 its FERC Order No. 784, "Third-Party Provision of Ancillary Services; Accounting and Financial Reporting for New Electric Storage Technologies". FERC Order No. 784 mandated reforms in grid "ancillary service" markets that are provided by FERC-regulated transmission providers, thus creating new business opportunities for energy storage technologies that can supply regulation and frequency response service forms of grid ancillary services.

Energy systems for storage contain large amounts of energy and typically provide power for three or four hours. This makes them suitable for peak shaving, load shifting, and ramping, which are helpful in mitigating the impact of intermittent energy sources like wind and solar on the grid. For example, wind blows predominantly at night. In fact, on the average, little of the nominal wind capacity is available during peak load periods. Summer heat can present the grid with midday demands it cannot satisfy without brownouts or denial of service. During morning and evening hours when photovoltaic (PV) generation is rapidly increasing or decreasing large ramps may occur which utilities can only follow with difficulty. This was the reason for California's recent 1.3GW mandate for storage. In all these situations energy storage with multiple hours of storage capacity can provide stability to the grid. Lithium-ion batteries and advanced lead-acid batteries can provide this service. But, perhaps, the most suitable technology is represented by the family of flow batteries. Zinc-bromine, iron-chromium, and vanadium-vanadium are among the available options being explored.

The ARRA program featured several projects providing multi-hour storage connected with wind and solar. One of the biggest lithium-ion facilities is an 8MW/4 hour project with Southern California Edison in Tehachapi, CA. It is situated next to one of the world's biggest wind fields. Currently this facility is exploring the whole suite of business cases for energy storage. OE also funded a number of promising start-ups in this area. Notable among these is Aquion, a small company developing a novel aqueous hybrid ion battery which is now in commercial production. This technology has not only attracted very substantial venture capital, but also led to the employment of over one hundred technical personnel.

Material Science

The OE energy storage program develops technology from material science, to the design of devices and system. Activities are all firmly focused on commercialization and eventual transfer to the market place. The program has generated over 90 peer reviewed publications in the last four years, as well as some 45 patents. A wide variety of chemistries are being investigated at Pacific Northwest National Laboratory (PNNL), Sandia National Laboratories, and Oak Ridge National Laboratory (ORNL). Universities participate through special sub-contracts with recognized experts in the field. As an example, University of Illinois is working on 2-electron transfer redox reactions in hybrid sodium-based flow batteries, potentially a breakthrough technology leading to a substantial increase of efficiency and cost reduction. SBIR projects are also firmly integrated into the programmatic structure, taking part in peer reviews, interacting with storage systems developers, and winning international recognition through R&D 100 awards, a recognition of the 100 top technology products of the year worldwide.

A particularly promising line of research concerns vanadium flow batteries. PNNL discovered that a mixed electrolyte consisting of sulfuric and hydrochloric acid makes the resultant system much more stable. This doubles the energy density and allows an appreciably bigger temperature window. PNNL has been developing this system for the past five years driving down the system cost from $650/kWh to $325/kWh thus reaching commercial viability. The cutting edge technology has been licensed to 5 companies for commercial production and transfer to the private sector.

Using a flow battery analysis model reveals that further cost reductions will need to come from the cost of the material. A promising candidate is zinc-iodide, potentially yielding five times the energy density of zinc-bromide. Other systems being investigated for technical feasibility and cost effectiveness are organics and organo-metallic structures. Another candidate for cost reduction is the membrane that is crucial in the rechargeable electrochemical cell. Research at Sandia has found a durable polymer film that may be two orders of magnitude more cost effective than Nafion, the currently used material. Tests with a vanadium system show that the material also lasts substantially longer than Nafion.

Because power electronics may be responsible for as much as 25 percent of the cost of a storage system, OE's energy storage program actively pursues research on advanced power electronics. Beyond the common silicon devices, so called "wide band gap" materials such as silicon-carbide and gallium- nitride offer a vastly improved footprint and much higher operating temperature, potentially resulting in substantial cost reductions. OE has an ongoing research program with small companies that have established many firsts in the field and brought technology to market. This work, at the cutting edge of technology, has been recognized through numerous R&D 100 awards.

Resiliency and State Projects

Natural disasters like hurricanes Sandy and Katrina have brought into focus the importance of emergency preparedness of the local electrical system. Experience has shown that diesel generators cannot always be relied on during emergencies. A more reliable solution is the formation of micro-grids which include both storage and renewable generation. Such a system can be islanded and provide critical services for extended time periods. But during normal times the storage facility can also provide demand management for the user and compensated services to the grid.

A system of this kind is currently nearing completion in Rutland, Vermont. Initiated through a joint solicitation by the Vermont Public Service Department and OE, the project will feature 4MW of storage integrated with 2MW of PV installed by Green Mountain Power. During disaster events the system will serve a high school/emergency center. At other times it will provide services to the grid. Rutland was subject to extensive flooding and long lasting electrical outages during tropical storm Irene in 2011. Although resilience is difficult to monetize, it is a strong motivating factor for this Vermont community.

Another OE state initiative is with Washington State. A solicitation by the Washington State Clean Energy Fund provided $15 million for three selected energy storage projects. All three projects involve technology developed with OE funding. Two of the projects, 1MW and 2MW respectively, use vanadium-vanadium flow battery technology as developed by PNNL and licensed to UniEnergy, a Washington based start-up company. The other project uses a zinc bromine battery developed with ARRA funding. Under a memorandum of understanding (MOU) between OE and Washington State, PNNL will develop a detailed cost benefit analysis of all three projects and suggest optimal economic use of the facilities. The next state planning a joint solicitation with OE is Oregon. Work with other states is under negotiation. One potential site is Florida, where OE is providing technical advice to the Kennedy Space Center for a possible micro-grid with storage and solar energy.

Industry Tools

With growing demand, new storage systems are entering the market and many of these are relatively unproven with respect to performance. OE has developed performance-based criteria and testing protocols with the consensus of the industry. OE is also providing a testing platform at Sandia where new storage systems up to 1MW can undergo comprehensive testing following standard load patterns based on various applications. The test center has provided help in establishing other test centers by private entities.

To keep track of the growing number of energy storage projects, OE has funded the establishment of the DOE Global Energy Storage Database. The database gives concise information on location, ownership, type of application, technology, and storage parameters. Owners of storage facilities enter their own data, but the input is vetted by experts. The database is internet based and free to storage providers and users, regulators, and the general public. There are now over 1,200 entries reporting projects from 58 countries. The searchable database is proving a valuable tool for regulators who are faced with accommodating the changing generation mix and the application of unfamiliar storage technologies.

As more and more projects are being deployed and an increasing number of vendors are entering the market it is becoming of paramount importance to develop proper safety codes. While the technology is generally safe, accidents have happened. Yet, there are at present no codes and standards specifically dedicated to grid-scale energy storage safety. For this reason OE convened a workshop last year, attended by scientists, the utilities, storage vendors, firefighters, and the insurance industry, to define the issue and make safety recommendations. Based on this input, OE has produced an Energy Storage Safety Strategic Plan to outline needed work in this field. A working group of leading experts from the various relevant professional institutions has been established under OE leadership. The group will determine priorities for needed research and form a core of future committees with wider public participation. Eventually this effort will lead to an accepted and coherent set of codes and standards to guide the industry.

Conclusion

DOE has provided leadership in establishing energy storage as an effective tool for promoting grid reliability, resiliency, and better grid asset utilization of renewable energy. The program has developed new cost effective storage technologies that industry has commercialized. Through field test and highly leveraged deployment, OE has opened new benefit streams and developed optimization tools for storage projects. The program has contributed to the establishment of new regulatory structures and is developing codes and standards for safety. OE is providing input into major solicitations driven by state mandates, such as those of California and Hawaii, and is partnering with other states in pioneering storage projects. DOE's leadership in creating a storage industry is widely recognized in the U.S. as well as abroad.

Although grid energy storage has made a creditable beginning, much remains to be done. More cost effective technologies need to be developed and available benefit streams need to be fully monetized. Institutional barriers to storage deployment need consideration. Greater storage system safety must be assured through development of a body of storage specific codes and standards. Public-private partnerships and joint solicitations with the states need to bring technical expertise at the National Laboratories within reach of private industry to establish storage projects in diverse geographic areas and for diverse applications.

DOE looks forward to continuing this important work. As our electric grid evolves, we expect that energy storage will be an integral component in assuring that electricity delivery for communities will be more flexible, secure, reliable, and environmentally responsive.

Mr. Chairman, and members of the Committee, this completes my prepared statement. I would be happy to answer any questions you may have at this time.

Dr. Imre Gyuk, U.S. Department of Energy

After taking a B.S. from Fordham University, Dr. Gyuk did graduate work at Brown University on Superconductivity. Having received a Ph.D. in Theoretical Particle Physics from Purdue University he became a Research Associate at Syracuse. As an Assistant Professor he taught Physics, Civil Engineering, and Environmental Architecture at the University of Wisconsin. Dr. Gyuk became an Associate Professor in the Department of Physics at Kuwait University where he became interested in issues of sustainability.

Dr. Gyuk joined the Department of Energy to manage the Thermal and Physical Storage program. For the past decade he has directed the Electrical Energy Storage research program in the Office of Electricity which develops a wide portfolio of storage technologies for a broad spectrum of applications. As part of the program he also supervises the $185M ARRA stimulus funding for Grid Scale Energy Storage Demonstrations. He is internationally recognized as an expert on storage technology.

Chairman WEBER. Thank the doctor. And we're going to move to our second witness, Dr. Virden.

TESTIMONY OF DR. JUD VIRDEN, JR., ASSOCIATE LABORATORY DIRECTOR FOR ENERGY AND ENVIRONMENT DIRECTORATE, PACIFIC NORTHWEST NATIONAL LABORATORY

Dr. VIRDEN. Chairman Smith, Chairman Weber, Ranking Member Grayson, and Members of the Subcommittee, thank you for the opportunity to testify in today's hearing.

My primary message today is that, even with the tremendous amount of excitement about the emerging U.S. energy storage market, there is still plenty of need for R&D innovations that increase performance, reduce lifecycle costs, and improve safety of the next generation of battery storage technologies. The presence of Aquion and Ambri here are evidence to the role of innovative researchers. For our part, I am very proud of PNNL's battery scientists and engineers who have produced close to 300 publications, have filed 91 United States patents, with 19 granted so far, and seven licenses to U.S.-based companies in Washington State, California, and Massachusetts. One of these companies, Unit Energy Technologies, or UET, was started by two former PNNL employees, scientists, in 2012. UET has grown to 50 employees, and they are now deploying their novel redox flow battery technology in Washington, California, and Germany.

PNNL recently published the first Institute Scientific Investigation, looking at the atomic level changes in lithium ion batteries that enabled us to visualize why they short-out and fail. The expected lifetime of lithium ion battery systems today is generally believed to be 5 to 7 years, and grid storage batteries will need to last ideally 15 to 20 years. This groundbreaking work also confirmed a new approach that might dramatically extend the lifetime of lithium ion batteries. But despite all these advances, we still have fundamental gaps in our understanding of the basic processes that influence battery operation, performance, limitations, and failures.

As you know, renewable energy creates many challenges for grid operations. Their generation profile does not match up exactly with demand, and their generation is intermittent. In the Pacific Northwest, we have five gigawatts of wind, and sometimes hundreds of megawatts or even gigawatts of RAMs. Texas has the same problem with wind, and California with solar. Battery storage could solve these problems by smoothing out the intermittent generation, and storing energy off-peak to be used later when it was most needed. Several of our PNNL studies have concluded that for battery storage to be viable, it must serve multiple grid applications, such as meeting energy demands minute-by-minute, hour-by-hour, storing renewable energy at night for use the next day, as well as deferring transmission and distribution upgrades. Utilities would like battery storage to deliver both high power and lots of energy. This is like wanting a car that has the power of a Corvette, the fuel efficiency of a Chevy Malibu, and the price tag of a Chevy Spark. This is hard to do. No one battery delivers both high power and high energy, at least not very well or for very long. There are many different types of battery chemistries and sizes of batteries. In demonstrations around the country, I have counted over 13 different types and sizes of batteries being explored. All are in different stages of development, validation, and demonstration for grid applications.

While today's batteries can address the higher value-added grid applications, the cost of batteries need to be reduced, the lifetime expanded, and the safety validated. We believe there are three key research and development challenges that need to be addressed to significantly improve existing advanced battery systems in the near term, along with the longer term development of the next generation, lower cost battery systems.

First, to provide confidence to utilities that new battery technologies will meet multiple grid applications, we need independent testing and evaluation of energy storage facilities to validate performance and safety, along with the continued development of codes and standards that allow interoperability between different technologies and software.

Secondly, continued support for basic and applied R&D is needed to discover new battery systems, and to better understand and predict why batteries don't perform as expected, why performance degrades over time, or why they fail. Universities and national labs across the country are well positioned to address the gap in our lack of fundamental understanding.

Finally, as new technologies make it out of the lab, we will need regional field demonstrations that validate the lifecycle costs, performance, safety, and overall impact on—batteries will have on reliability, resiliency, and renewable integration. This information is critical to feed back to those developing the next generation of batteries.

Thank you for the opportunity to testify, and I'd be happy to answer any questions.

[The prepared statement of Dr. Virden follows:]

Written Statement of

Jud Virden, Ph.D.
Associate Laboratory Director, Energy & Environment Directorate
Pacific Northwest National Laboratory

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

Hearing on:
Innovation in Battery Storage for Renewable Energy

May 1, 2015

Introduction

Chairman Weber, Ranking Member Grayson, and Members of the Subcommittee, thank you for the opportunity to testify in today's hearing on *Innovations in Battery Storage for Renewable Energy.*

My name is Jud Virden, and I am the Associate Laboratory Director for Energy and Environmental research at Pacific Northwest National Laboratory (PNNL) in Washington State. PNNL is a U.S. Department of Energy, Office of Science multi-program national laboratory operated by Battelle.

My comments will focus on four main areas:

1. The current state of the grid energy storage research at PNNL, including the primary areas of battery technology and chemistry being explored.
2. Key technology breakthroughs achieved through PNNL's work on grid energy storage and how we have transferred those breakthroughs to the private sector.
3. Next steps in research and development (R&D) and technology deployment necessary to meet stated goals for grid energy storage performance.
4. The impact that these new technologies can have on the energy market, particularly renewable power, if stated goals are met.

Current State of Grid Energy Storage Research at PNNL

PNNL's Grid Energy Storage program covers a broad spectrum of research and development. Our scientists focus on the development and application of unique scientific tools and computational models to understand fundamental material and chemical processes in batteries. Our material scientists and engineers develop new battery materials, and perform testing and evaluation of novel prototype battery systems. Our grid system engineers perform system analysis to predict the cost and performance requirements for energy storage grid applications, along with the development of consistent testing protocols, safety codes, and standards. We collaborate with universities, utilities, battery providers, software developers, and state governments. These integrated efforts are focused on creating energy storage technologies that will enable our future grid to be more resilient, reliable, secure, and flexible so that it can incorporate more renewable energy, utilize loads as a resource, and provide enhanced resilience against energy outages.

Our primary sponsors for grid energy storage research are the Department of Energy's Office of Electricity and Office of Science. PNNL supports the Office of Electricity through research and development of next-generation cost-competitive energy storage technologies, and validated reliability, safety, and industry acceptance of those technologies. With support from the Office of Science's Basic Energy Science (BES), PNNL is a key member of the Joint Center for Energy Storage Research (JCESR) led by Argonne National Laboratory. In JCESR, we collaborate with Lawrence Berkeley National Laboratory and Sandia National Laboratories, University of Michigan, Stanford, Massachusetts Institute of Technology, and many other partners. The Office of Science also supports an Energy Frontier Research Center (EFRC) at PNNL: the Center for Molecular Electrocatalysis. This center aims to develop low-cost catalysts to replace precious metals for energy conversion and storage. We utilize the Environmental Molecular Science Laboratory (EMSL) at PNNL, which is a Department of Energy, Office of Biological and Environmental Research national scientific user facility. EMSL's mission is to enable molecular-level discoveries that translate to predictive understanding and accelerated solutions for national energy and environmental challenges. Through the DOE Office of Energy Efficiency and Renewable Energy's (EERE) role in the DOE Grid Modernization Laboratory Consortium, PNNL evaluates integration of renewable on the grid including energy storage. PNNL evaluates a variety of energy storage options through EERE's Building Technology Office in combination with transactive control of buildings to mitigate renewable generation variability.

PNNL's scientific R&D is focused on electrochemical energy storage (batteries). Specifically, we are involved in the scientific understanding and development of a variety of next-generation low-cost battery chemistries including aqueous and nonaqueous redox flow (vanadium, zinc-iodine), lithium ion, lithium-sulfur, and sodium batteries.

Technology breakthroughs and their transfer to private industry

Since 2009, PNNL's grid-scale energy storage research has led to more than 298 publications, 216 invention reports, 91 U.S. patents filed, 19 patents granted to date, and seven licenses to U.S. based companies. It is our outstanding technical staff, in combination with state-of-the-art characterization tools, modeling and simulation capabilities, and testing protocols that allows us to rapidly transform fundamental discoveries into practical applications.

PNNL scientific research and development. Today, we cannot predict — based on scientific principles — the performance of new battery systems. Understanding the atomic- and molecular-level processes that govern their operation, performance limitations, and failure processes is one of critical areas of battery research being addressed by scientific institutions around the world. To develop this understanding will require advances in situ tools and techniques that, in combination with advanced modeling and simulation, allow us to first see and then predict how atoms and molecules change structures and react under real-world operating conditions.

With Office of Science funding, and by taking advantage of the scientific capabilities at EMSL, PNNL is pioneering in situ transmission electron microscopy (TEM) to attack this challenge. TEM allows scientists to see the atomic and molecular processes that influence battery performance and lifetime. In situ characterization techniques allow scientists to see how battery materials are changing under real operating conditions while charging and discharging — as opposed to the old approach where we had to charge and discharge a battery, then take it apart and characterize the materials to try to figure out what happened. We are applying this new technique to several battery materials under a variety of DOE projects and, with additional improvements to the approach, will provide the world with some of the first views of fundamental material and chemical processes in a battery while the battery is charging and discharging. Using this technique, scientists at PNNL recently published the first in situ study of why lithium ion batteries short out and fail. This groundbreaking work also has confirmed a new approach that might dramatically extend the lifetime of lithium batteries.

PNNL scientists also have utilized a wide range of state-of-the-art nuclear magnetic resonance (NMR) spectrometers, including a unique micro-battery design for studying battery chemistry under realistic conditions. NMR allows researchers to measure how battery chemistry is changing under battery operation. Changes in materials chemistry often lead to loss of capacity and reduced battery life. PNNL applied NMR techniques to understand the fundamental chemistry in the novel mix acid redox flow battery, and we are currently applying NMR, TEM, and other techniques to help understand the electrolyte chemistry in advanced energy storage materials as part of the JCESR.

PNNL breakthrough transferred to the private sector. One of our most recent exciting breakthroughs coming out of PNNL is the development of a mixed acid vanadium redox flow battery that increased energy capacity by 70 percent with a much wider temperature range of operation, making it significantly more practical for real-world applications. The approach was especially exciting because the mixed acid chemistry in this battery went against mainstream thinking, opening a new and promising area of battery development. This research started with DOE Office of Electricity funding to explore new approaches to dramatically improve flow battery performance. The research leveraged scientific staff and advanced characterization tools at the Office of Science's EMSL user facility.

Through an approach that involved both theoretical computations and experimental validation, PNNL scientists and engineers evaluated many electrolyte options, ultimately determining that the mixed acid system promised the most dramatic improvements. Five small U.S.-based companies (based in Washington State, California, and Massachusetts) have subsequently licensed the PNNL technology and are further developing it for private sector grid applications. One of those companies, UniEnergy Technologies (UET), was started by two former PNNL scientists in 2012, and has grown to 50 employees. UET is deploying its novel flow battery technology in Washington, California, and Germany. UET's project with Avista Utilities in Pullman, Wash., was featured last week in the New York Times (*Liquid Batteries for Solar and Wind Power*, April 22, 2015). The $7 million demonstration project on the Schweitzer Engineering Laboratories campus is being tested as an uninterruptible power supply: In case of a power failure, the batteries in UET's storage containers can keep the company's manufacturing operations running for three hours.

PNNL testing, evaluation, and validation activities. PNNL is also involved in several regional activities to independently test and evaluate battery system performance in real grid applications. In the Pacific Northwest, as part of Washington State's Clean Energy Fund, PNNL has been asked to perform technical and economic use case analyses, dispatch optimization, and performance monitoring in collaboration with three regional utilities that are deploying energy storage technologies in the field. In another example, PNNL worked with Puget Sound Energy to address four questions relative to the practical deployment of energy storage on the grid: 1) Where should energy storage be sited and at what scale to maximize value in the Puget Sound Energy system? 2) What services can energy storage provide and what values are derived from these services? 3) How do we build and test an energy storage control strategy to maximize value? And, 4) When optimized to maximize value, do the modeled benefits exceed the revenue requirement for the battery system? Our analysis of several sites determined a single site where a 3MW (9-12 MWh) battery system would yield a positive return based on reducing outage mitigation, capacity value, deferral upgrades, and inter-hour balancing.

Energy storage and renewable generations. Energy storage also can smooth out the fluctuations in power flow caused by the variable nature of wind and solar sources. PNNL performed a high level study (PNNL report 21388) for the DOE Office of Electricity, determining that more than 18.6GW of additional inter-hour balancing capacity is needed if renewables represented 20 percent of U.S. generation capacity by 2020. Energy storage would be key to enabling high market penetration. The study also highlighted the need for lower cost energy storage technologies to compete effectively against other technologies such as combustion turbines and demand response.

Finally, PNNL is working with DOE and Sandia National Laboratories to develop proposed testing and evaluation protocols (*Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems*, PNNL-22010). PNNL also is actively involved in the development and deployment of codes, standards, and regulations affecting energy storage system safety (PNNL reports 23578 and 23618). These DOE Office of Electricity activities are critical to building consistency and uniformity in evaluating and ultimately deploying new battery technologies

What next steps in R&D and technology deployment are necessary to meet stated goals for grid energy storage performance?

The key research and development issues that need to be addressed for near-term deployment of advanced batteries and for longer-term next-generation energy storage include:

1. *Key Scientific Challenges*. Sustained fundamental science and applied research continues to improve the tools and techniques available to develop the next generation of safe, low-cost, high-performance grid energy storage technologies.
2. *Key Development Challenges*. Independent evaluation and validation of next-generation energy storage technologies to validate cost, performance, and safety over and the continued development of uniform codes and standards that allow interoperability between different technologies and software.

3. *Key Demonstration Challenges.* Regional demonstrations of energy storage for multiple grid applications that validate the life-cycle cost, performance, safety and overall impact of batteries on grid reliability, resilience, and renewable integration.

Key scientific challenges and next steps. We cannot predict, based on scientific principles alone, the performance of new battery systems. Battery systems consistently perform well below their theoretical potential. In 2007, the Department of Energy assembled experts from throughout the U.S. and the world to assess the basic research needs for electrical energy storage. While many advances have been made in the last eight years, the primary conclusions of the report (*Basic Research Needs for Electrical Energy Storage, Department of Energy, Office of Science, Basic Energy Sciences, 2007)* are still valid and represent the key challenges to be addressed over the next several decades:

> *...Although electrical energy storage devices have been available for many decades, there are many fundamental gaps in understanding the atomic- and molecular level processes that govern their operation, performance limitations, and failure. Fundamental research is critically needed to uncover the underlying principles that govern these complex and interrelated processes. With a full understanding of these processes, new concepts can be formulated for addressing present electrical energy storage technology gaps and meeting future energy storage requirements.*

The report also calls out four critical crosscutting research directions required to meet future technology needs for electrical energy storage: advances in characterization, nanostructured materials, innovations in electrolytes, and theory, modeling, and simulation. In addition to EMSL, other scientific user facilities play an important role in advancing this research, including: National Synchrotron Light Source (NSLS) at Brookhaven National Laboratory, Integrated Center for Nanotechnologies (CINT) at Sandia National Laboratories, and Advanced Photon Source at Argonne National Laboratory.

PNNL strongly supports the continued and focused efforts of the scientific community to address these scientific challenges and research directions. New breakthroughs based on an improved fundamental understanding will take many years to ultimately yield low-cost, high-performance, safe batteries for all grid applications. There must also be a focus on the applied sciences to accelerate the transfer of fundamental understanding to new battery systems. This is best accomplished by testing new materials systems in small-scale prototypes under real-word grid operating conditions. The information gained from this small system testing capability provides the feedback loop needed for scientists and engineers to rapidly close the gap between the often-high theoretical potential of a new material and the much lower practical energy storage capacity and lifetime demonstrated in real-world systems.

Key development challenges and next steps. There are more than 3,000 utilities in the U.S. with different grid challenges (transmission and distribution congestion, peak demand, renewable integration, severe weather events, etc.), depending on location, energy mix, and infrastructure. Most have little or no R&D capacity, and cannot assume the large amount of risk inherent in developing and testing new energy storage materials or in validating their performance or safety without passing those costs on to consumers. We consistently hear from utilities and state governments that an independent evaluation and validation of next-generation energy storage technologies is needed to provide confidence in new battery performance and safety. Along with this is a need for uniform codes and standards that allow interoperability between different technologies and software interfaces. This is key to ensure that new technologies can plug and play into the existing grid operations system.

We believe that more efforts need to focus on independent testing and validation of new battery technology for grid applications. This would involve independent testing at a cell level, stack level and system level. Testing and evaluation also needs to include validation of both the power control system and the software that interfaces to existing utility management systems. Consistent codes and standards that allow multiple technology options (there are many types of batteries) while still providing interoperability between all technologies (i.e., plug and play) are important for an emerging market.

Key demonstration challenges and next steps. Energy storage demonstrations are taking place around the country, but we will need more. Most are supported by federal or state funding, sharing the risk with utilities. Most demonstrations are for higher value grid applications. As new lower cost energy storage technologies are developed over the next decade, demonstrations will still be important to build confidence in performance, lifetime, safety, and benefit to multiple low-cost grid applications.

Continued demonstrations of energy storage for multiple grid applications are needed, in different regions of the U.S., to build confidence that energy storage is a viable technology option. Demonstrations that focus on validating life-cycle cost, performance, and safety for multiple grid applications, and that assess the overall benefit relative to grid reliability, resilience and renewable integration, are critical to both long-term and near-term success in getting energy storage technology deployed on the grid. Ideally, lessons learned would be shared across the entire utility community to enable utilities with limited resources and opportunity to more effectively and efficiently determine where energy storage can contribute to their grid applications.

What impact could these new technologies have on the energy market, particularly renewable power, if stated goals are met?

Electric energy storage has long been the "holy grail" for grid operators. The ability to store electrons at the distribution and transmission level would allow an unprecedented ability to fully utilize both centralized and distributed renewable energy. Energy storage will also allow grid to improved reliability and resiliency, by meeting a variety of services. Grid energy storage can improve both grid reliability and resilience by providing a local "cushion" against shocks to the system caused by interruption of generation or by loss of circuit connection at either the bulk (transmission) system level or in the more local distribution system. Local energy storage can buffer users from short-term power problems by supplying the necessary energy and ancillary services needed to provide "ride-through" during system events and help in re-stabilizing the grid. Finally, energy storage adds flexibility in how we collect and use electric energy, even providing energy usage time shifting where needed in order to better match variable sources to variable loads. Overall, the industry has identified more than 30 uses for electric storage on the grid, making the combination of storage, power electronics, and advanced controls into a new general-purpose grid component that is as fundamental as a transformer or a circuit breaker.

There are a variety of analyses in the public literature that estimate the size of the future global energy market. A 2010 report by the Electric Power Research Institute (*Electric Energy Storage Technology Options; A Primer on Applications, Costs & Benefits*) describes a 50GW market size (roughly ranging from \$5 billion to \$25 billion) if low-cost (\$100/kWh to \$500/kWh) energy storage technologies can be developed and deployed. Other estimates forecast worldwide markets exceeding \$100 billion over the next five years.

Summary

The U.S. electric grid and U.S. citizens would benefit greatly from the widespread use of low-cost, reliable, and safe energy storage. It will truly enable distributed and centralized renewable energy, while increasing transmission and distribution reliability and resiliency. While there are early high-value-added market grid applications for energy storage along with an emerging collection of U.S. battery providers, there still is a need to dramatically reduce the cost of effective energy storage over the long-term. Unlocking the full potential of U.S. researchers to address the fundamentals of energy storage, discover new materials, and rapidly translate these discoveries into practical applications is necessary to ensure that new technologies are U.S. born and raised.

Thank you again for the opportunity to testify. I look forward to answering any questions you may have.

Jud W. Virden Jr., Ph.D.
Associate Laboratory Director
Energy and Environment Directorate
Pacific Northwest National Laboratory
Richland, Washington

Jud W. Virden Jr., Ph.D., has served since 2011 as the Associate Laboratory Director for the Energy and Environment Directorate at Pacific Northwest National Laboratory (PNNL) in Richland, Wash. PNNL has been operated since 1965 by Battelle for the U.S. Department of Energy.

Dr. Virden leads about 1,000 scientists, engineers, and professional staff in delivering science and technology solutions for the nation's energy and environmental challenges. He is responsible for a $234 million research portfolio spanning Clean Fossil Energy, Electricity Infrastructure (including grid-scale energy storage), Energy Efficiency and Renewable Energy, Environmental Health and Remediation, and Nuclear Energy and Science.

He has contributed to several national and international public/private technology partnerships. In 2009, he was assigned to DOE Headquarters to assist in the development of U.S.-China clean energy research centers. In 2000, Dr. Virden served as co-chair for the DOE 21st Century Truck Partnership National Laboratory Council, working with 18 industry partners and national research institutions to create a national technology roadmap and research partnerships with National Laboratories to reduce heavy duty truck emissions and increase vehicle efficiency. In 1994, he served on a two-year assignment in Flint, Mich., working with the United States Council for Automotive Research, GM, Ford, and Chrysler, where he was part of a team that initiated and developed multiple government/industry projects to address next-generation vehicle technologies.

Since joining PNNL in 1991 as a researcher, Dr. Virden has served in a variety of technical and managerial positions. His honors include R&D 100 and Federal Laboratory Consortium awards, an MIT Discover Award, and a Financial Times Global Automotive Award with Delphi Automotive. He was inducted in 2014 into the Washington State Academy of Sciences. He currently serves on the following boards and advisory committees: the American Council for an Energy Efficient Economy, Council for Chemical Research, Georgia Tech Strategic Energy Institute, University of Michigan Energy Institute, University of Washington College of Engineering, CleanTech Alliance Washington, and Oregon BEST.

Dr. Virden holds a bachelor's degree and a doctorate degree in Chemical Engineering, each from the University of Washington.

Chairman WEBER. Thank you, Dr. Virden. Mr. Giudice, you are recognized for five minutes.

TESTIMONY OF MR. PHIL GIUDICE, CHIEF EXECUTIVE OFFICER, AMBRI

Mr. GIUDICE. Thank you, Chairman Weber, Chairman Smith, and Ranking Member Grayson, I appreciate the opportunity to testify today.

I'm the CEO, President, Board Member of Ambri, and as you know by having this hearing, energy storage has the potential to transform our electricity grid in very positive and productive ways. Right now, the grid needs to meet, for every instant of the day, everywhere, the supply of electricity with the demand for electricity, and storage will change everything.

Today in the United States, one of the ways we meet our peak demand is through simple cycle combustion turbines, and the capacity factor for those engines is two percent. Literally only 160 hours a year are those engines being driven to meet the peak demands, and storage could change everything. If we are able to meet average demand instead of peak demand, we could actually reduce the amount of grid infrastructure investment by approximately 1/2 of what our traditional market is.

So there are many different ways that storage could help. I'm going to suggest six different areas for federal government leadership that would be particularly of interest, and I'll give you a little story about Ambri in the context of that.

First is ARPA–E Programs. So ARPA–E funded campus research at MIT, Dr. Sadoway, to look at a very interesting application for the—his life's work, which was electrometallurgical refining. And basically, he took the same kinds of processes that are known in the aluminum smelter world of taking a ton of dirt and running electricity through it to produce pure aluminum metal at 50 cents a pound, and said what if we could make those processes reversible so that we're not only taking enormous amounts of electricity off the grid, but we could turn around and put it back on the grid. And it was kind of an interesting concept, a White Paper sort of exercise, a—that attracted funding from ARPA–E in 2007/2008 time frame. The $7 million grant from ARPA–E made all the difference in the world. This was a concept that there was no private money, no other public money, that was willing to step up and see if this idea could work. With that investment, plus other private sources, Dr. Sadoway, and then Dr. Bradwell, were able to drive research on campus to actually prove that this concept works, and works rather remarkably. They had a team that was up to 20 folks on campus advancing this technology, which then enabled the company to come together as a private enterprise and seek private financing. We are now 50 people, and completely privately financed with investments from Bill Gates, Total, Khosla Ventures, the—KLP Enterprises and GVB, and we employ 50 folks and we're out there now delivering our technology to the marketplace. So we're—we were formed in 2010, we're just now manufacturing our prototypes, and we'll begin delivering them this fall. And those go to very interesting customers, including the U.S. Department of Defense in Massachusetts and Connecticut, the Joint Base Cape Cod and sub-base in Groton, Connecticut, Con Ed in New York, Alaska Energy Authority in Alaska, and then in Hawaii, two prototypes are going—are scheduled to go there end of this year/beginning of next year, as well as our first 1 megawatt hour battery storage solution to the U.S. Navy at Pearl Harbor towards the end of 2016.

So this federal money that was able to sort of get behind a concept, and become sort of an interesting possible technology, is now developing itself and being delivered into the commercial marketplace, and looking very, very attractive.

So one role I encourage is continued support for ARPA–E and the work that they're doing. Another—five other possibilities include continued support on demonstration projects through the Department of Defense and the Department of Energy. Third is to continue work with States and Federal Energy Regulatory Commission to help them understand and appreciate the full value of storage. There's a very clear and compelling need between States' roles and rights, and the federal government in terms of helping to educate and appreciate the value that storage can provide. And then two other areas I'd touch on. One is the Loan Guarantee Program which, of course, has gotten a lot of coverage, I think plays a very interesting role and could be very helpful for storage, both from manufacturing and demonstration projects. Federal tax credits and—including in master limited partnership clean energy investments as possibilities to help this nascent technology that the United States, in fact, has the best research going on and the best new companies starting to really bear full fruit and become a world-dominant provider.

So I am excited to be here today, and look forward to taking any questions that you might have. Thank you.

[The prepared statement of Mr. Giudice follows:]

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Testimony before the

Hearing of the House Committee on Science, Space and Technology

Innovation in Battery Storage for Renewable Energy

May 1, 2015

Submitted by:
Phil Giudice,
Chief Executive Officer, President and Board Member
Ambri Inc.

Chairman Smith, Ranking Member Johnson, and other Members of the Committee, thank you for this opportunity to share my perspectives on the opportunity for energy storage and the role of Federal energy leadership in today's energy industry.

I am the Chief Executive Officer, President and Board Member of Ambri Inc., an early-stage company commercializing a new type of energy storage technology – the Liquid Metal Battery (LMB) – invented at the Massachusetts Institute of Technology (MIT). I have worked in the energy industry for 39 years as a business manager, entrepreneur, and public servant. I started my career as an exploration geologist for Chevron; I was a management consultant for 20 years and led Mercer Management Consulting's Global Utilities practice (now known as Oliver Wyman); I was a founding Board Member and Senior Vice President at EnerNOC; and I was Undersecretary of Energy and Commissioner of the Department of Energy Resources for the Commonwealth of Massachusetts. I have also served the U.S. Department of Energy (DOE) as a Board Member for the State Energy Advisory Board for five years and as a committee member of the Energy Efficiency and Renewable Energy Advisory Committee (ERAC); I am a leadership group member for the U.S. Environmental Protection Agency (EPA) and the U.S. DOE's National Action Plan for Energy Efficiency.

I have a deep appreciation for the very many challenges the electricity industry faces and the role of public policy in energy, and I am encouraged about the potential for energy storage to be a transformative solution for many of the industry's challenges.

Energy storage promises to fundamentally transform the way our electricity system works by decoupling the supply and demand of electricity and enabling a more efficient, more reliable and less expensive system with significant quantities of renewable resources.

Today, electricity supply needs to meet electricity demand every instant of every day, everywhere. To do this, our electric system is built to meet peak demand plus a reserve margin. In many systems, 10 percent or more of the generating capacity and corresponding infrastructure is built to meet demand levels that occur in less than one

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percent of the hours in the year.[1] In the U.S., 50 percent of simple cycle combustion turbines have capacity factors below 2 percent, meaning that those plants are operating less than 2 percent of the hours of the year.[2]

With energy storage, rather than building infrastructure to meet peak demand, we can accommodate fluctuations in demand with storage and as a result build our generation, transmission, and distribution infrastructure to meet our average demand. For instance our average electricity demand in the U.S., is approximately 60% less than our peak generating capacity.[3]

Energy storage promises a variety of benefits; there are many reports that have been published that enumerate the grid services energy storage provides.[4] These include, for example:

- Time shifting energy from one period to another; for example from a period when there is ample renewable output to a period when the sun isn't shining or the wind isn't blowing; or from a period when prices are low to a period when prices are high on a wholesale power market;
- Providing ancillary services like frequency regulation (to moderate the moderate second-to-second fluctuations in grid frequency and voltage to enhance reliability), ramping capability (to mitigate the impacts of intermittent renewable generation output on the grid) and voltage support;
- Reducing end user electricity costs by mitigating peak demand and optimizing time of use tariffs;
- Providing capacity to offset the need for traditional generation infrastructure;
- Reducing transmission and distribution (T&D) congestion to offset or defer the need for traditional T&D infrastructure; and
- Increasing reliability by enabling the electric grid stability to become much less critically dependent on distant generation and transmission system.

Ambri's story is one of a successful public-private partnership to date. Our experience and the challenges that remain are indicative of a set of policy considerations and recommendations we have for this Committee:

1. *Sustain and increase support for the DOE's Advanced Research Projects Agency for Energy (ARPA-E);*

2. *Increase support of DOE and Department of Defense (DoD) technology demonstration initiatives;*

[1] See, for example, ISO New England load data for 2014, where over 11 percent of capacity was required to supply the top one percent of hours; available at http://www.iso-ne.com/markets/hstdata/znl_info/hourly/smd_hourly.xls.
[2] U.S. Environmental Protection Agency Office of Air and Radiation, Capacity Factors for New Units, July 2010, p. 4; available at http://www.epa.gov/airtransport/pdfs/TSD_capacity_factors_analysis_for_new_units_7-6-10.pdf.
[3] See, U.S. annual electric power sales and peak demand data from the U.S. Energy Information Administration, available at http://www.eia.gov/electricity/annual/html/epa_01_02.html .
[4] See, for example, the "DOE/EPRI 2013 Electricity Storage Handbook" published by Sandia National Labs in July 2013; available at http://www.sandia.gov/ess/publications/SAND2013-5131.pdf.

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3. *Support DOE and Federal Energy Regulatory Commission (FERC) efforts to research and implement with the states supporting policies that enable energy storage to receive the full value for the services it provides;*

4. *Expand DOE's Loan Program Office's (LPO) Loan Guarantee Program to support energy storage projects and energy storage manufacturing by amending the authorizing legislation for the Renewable Energy and Energy Efficiency Loan Guarantee Program to mirror the Advanced Vehicle Manufacturing program;*

5. *Consider a declining, time-limited federal investment tax credit for energy storage to accelerate private sector investment in this nascent electricity technology; and*

6. *Support H.R. 1696 – Master Limited Partnerships Parity Act to expand Master Limited Partnership (MLP) designation to companies in the clean-tech industry.*

I'll address each one of these points in turn.

1) Sustained and increased support for ARPA-E

The DOE's ARPA-E program was pivotal for the development of the LMB technology; ARPA-E enabled significant basic science research on the LMB and the achievement of key milestones which were critical to forming the company Ambri Inc. and receiving funding from top-tier equity investors.

In 2006, Professor Donald Sadoway and his graduate student Dr. David Bradwell at MIT demonstrated the theoretical capability of the LMB in a paper study exploring the underlying electrochemical theory of the technology. This preliminary research was funded by a small grant from a private foundation. In 2009, Professor Sadoway received a $7 million grant from ARPA-E alongside cost-share from the Massachusetts Clean Energy Center. Importantly, this federal and state government funding catalyzed even more private sector funding for the on-campus research. Professor Sadoway was able to attract over $13 million in aggregate and grow his lab to more than 20 researchers. This team made substantial progress in understanding the basic science elements of the LMB technology and demonstrating its potential.

In 2010, Drs. Sadoway and Bradwell co-founded Ambri with initial investment from Bill Gates and Total. Ambri has raised over $50 million in equity financing in three rounds of investment, grown its workforce to 50 full-time employees, and expanded its footprint into two locations in Massachusetts, one for research and development in Cambridge and one for systems testing and manufacturing development in Marlborough. In addition to Bill Gates and Total, other investors include Khosla Ventures, KLP Enterprises (the family office of Karen Priztker and Michael Vlock) and Building Insurance Bern (GVB).

ARPA-E focuses on a critical stage in the development of high-potential energy technology and fills a funding gap between basic and applied research, where the theory has been demonstrated but is far from practical use. For the LMB, the ARPA-E grant came at a critical time in the development of the technology; there are other case

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studies where this is similarly the case. Without ARPA-E, it is likely that the LMB would not have attracted the necessary research capital to demonstrate its potential. Commercial funding sources or other public funding are simply not available for promising albeit speculative energy technologies. It is worthwhile and critical to invest in promising new technologies, and the U.S. government has and should continue to play a key role as a catalyst.

2) Increased support of DOE and DoD technology demonstration initiatives

The U.S. government – and in particular the U.S. DoD as the largest energy consumer in the world – can and should continue to play a key role in demonstrating the capabilities of new energy technologies. It is a completely appropriate and important role for Federal leadership to include new energy solutions in the mix of their energy choices. It is risky to simply rely entirely on conventional energy solutions; by funding demonstration projects of new technologies, the government will gain access to new solutions and develop insights about these solutions which can propel technology adoption.

For Ambri, successful early-stage deployments funded by state and Federal grants will validate the performance characteristics of our product and enable the company to achieve important operational milestones, de-risking the technology for market entry.

Today, with funding from Federal and local governments, Ambri is preparing to deploy products to customers across the country, with a range of customer segments including the military, electric utilities and renewable resource developers. These projects will be at the following locations:

- Joint Base Cape Cod in Massachusetts with funds from the Massachusetts Clean Energy Center;
- Naval Submarine Base (SUBASE) in New London, Connecticut with funding provided by the U.S. Navy;
- Con Edison, an electric distribution utility in New York City with funding provided by the New York State Energy Research and Development Authority;
- Multiple partners in Hawaii including SunEdison and the Joint Base Pearl Harbor Hickam with funding from the Energy Excelerator, a contractor for the Office of Naval Research, and the Navy's Expeditionary Warfare Center;
- University of Alaska in Fairbanks with funding from the Alaska Energy Authority.

3) Support for DOE and FERC efforts to research and implement policies that fully value energy storage

Energy storage provides value across many elements of the entire electricity value chain – generation, transmission, distribution and behind-the-meter. However, in many markets, the benefits of energy storage are not easily recognized or compensated. Clear regulatory policies will be important to fully and quickly realize the potential for storage to address electric industry challenges. Congress should encourage efforts at the DOE's Office of Electricity and the FERC to fully value storage, to provide guidance on removing regulatory hurdles for energy storage, and to work with the states to provide support and perspectives on helpful state regulations and policies for energy storage.

4) Expand the purview of the DOE's Loan Guarantee Program to support domestic manufacturing of energy storage technologies

The DOE's Loan Guarantee Program has delivered on its mandate of facilitating the adoption of new energy technologies which are not yet appropriate for available conventional commercial financing. We applaud the Loan Program Office (LPO) for its successes, including catalyzing the growth of large-scale photovoltaic projects in the United States, and supporting the development of domestic advanced technology vehicle manufacturing at Ford and Nissan.[5] To date, the Loan Program has been a net positive for the U.S. Government, accumulating $780 million in losses while earning $810 million from interest payments.[6]

A modestly revised Loan Guarantee Program would accelerate the adoption of energy storage technology and storage manufacturing jobs in U.S.

a) *Reduce the barriers to applying for a loan guarantee to enable developers of smaller-scale projects to take advantage of the program.* Today, there exist significant barriers to entry to the program, including high application fees; facility and maintenance fees; [7] substantial costs for legal, consulting and engineering services; and a lengthy application and review process. The DOE website says, "the application, due diligence, negotiation, and approval processes are time and capital-intensive."[8] For an early-stage technology company like Ambri, even after we have executed several successful demonstration projects as described above, conventional project financiers' risk tolerance will inhibit adoption of storage. Cost effective support from the Loan Guarantee Program could be a very helpful tool to finance Ambri's first commercial projects as well as bring advanced storage manufacturing jobs to the US.

b) *Support U.S. energy storage manufacturing by expanding the language of Section 1703 of Title XVII of the Energy Policy Act of 2005 to mirror the flexibility of Section 136 of the Energy Independence and Security Act of 2007.* Today, the existing Loan Guarantee Programs for renewable energy and energy efficiency technologies

[5] See article published by The Pew Charitable Trusts. "In 2009, no solar PV facilities larger than 20 megawatts were operating in the United States because developers could not secure the funding necessary to build them. To address this market barrier, the office provided $4.6 billion in loan guarantees to support the first five PV arrays larger than 100 MW. Since the end of the program in September 2011, 17 more large-scale installations have been financed without guarantees, and industry officials expect another 5 gigawatts of utility-scale PV to be built in 2015 alone." Available at http://www.pewtrusts.org/en/about/news-room/news/2015/04/21/federal-investment-is-key-to-growth-of-clean-energy-industry?hd&utm_campaign=2015-04-27%20CEBN&utm_medium=email&utm_source=Eloqua.

[6] See DOE Loan Program website; available at http://www.energy.gov/articles/energy-department-s-loan-portfolio-continues-strong-performance-while-deploying-innovation

[7] The Phase 1 application fee is $50,000; the Phase 2 application fee is $100,000 or $350,000 depending on the size of the loan guarantee requested. The facility fee is 1% of the loan guarantee amount up to $150,000,000 and 0.6% thereafter. The maintenance fee is expected to be up to $500,000 per year. See, http://energy.gov/sites/prod/files/2014/07/f17/Renewable%20Energy%20and%20Efficient%20Energy%20Projects%20Solicitation%20FINAL.pdf.

[8] See DOE Loan Program Office Website; available at http://energy.gov/lpo/renewable-energy-efficient-energy-projects-solicitation-faq.

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authorized by Section 1703 of Title XVII of the Energy Policy Act of 2005 do not support advanced manufacturing initiatives. However, the Advanced Technology Vehicles Manufacturing (ATVM) Loan Program authorized under Section 136 of the Energy Independence and Security Act of 2007 does support manufacturing initiatives.

5) Federal tax credits for energy storage

I firmly believe that the energy storage industry will not need subsidies or mandates to grow and thrive. However, an investment tax credit (ITC) for storage declining to zero over a prescribed period of years will accelerate storage development in U.S., encourage domestic companies to continue to run their businesses locally, and pull foreign companies to the U.S. for business resulting in more domestic jobs in manufacturing, engineering, and construction. Other countries such as Japan, Korea and Germany, acknowledging the industry's potential growth, have established significant subsidy programs for energy storage.[9] With a limited-time-horizon ITC, the United States will replace these countries as the world leader for energy storage and reap benefits long after the proposed ITC has expired.

6) *Support H.R. 1696 – Master Limited Partnerships Parity Act to expand MLP designation to companies in the clean-tech industry.*

MLPs enable corporations to avoid double taxation. That is, rather than being taxed once at the corporate level and once at the equity-holder level, and MLP will only be taxed at the equity-holder level. Today, MLP status is granted only to corporations involved in fossil fuel deployment, and this tax structure has attracted significant and relatively low-cost capital to the sector. Congress can pass H.R. 1696 enabling MLP status for corporations in the clean-tech sector to accelerate significant investment in a sector that is helping create a lower-cost and lower emissions energy future.

Thank you for taking the time to explore these issues, and I look forward to taking your questions.

[9] For example, in Japan, in January 2015, the Ministry of Economy, Trade and Industry introduced a $780 million program targeting energy storage and energy efficiency. South Korea in 2011 announced that it would invest US$5.94 billion by 2020 in developing the energy storage industry. Germany in May 2013 launched €25 million storage system incentive on new and retrofitted systems whereby up to 30 percent of equipment installation costs is subsidized, capped a 30 kW.

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PHIL GIUDICE BIOGRAPHY

Chief Executive Officer, President and Board Member

Phil Giudice is the CEO of Ambri. Ambri, formerly Liquid Metal Battery Corporation, is a technology company creating cost effective, reliable, wide spread grid electricity storage solutions, enabling separation of power demand from power supply. Phil has 39 years' experience in the energy industry as a geologist, consultant, executive, and state official. Phil was appointed by US Department of Energy Secretary Steven Chu to US DOE's Energy Efficiency and Renewables Advisory Committee, its State Energy Advisory Board, and Phil has served as a leadership group member for the U.S. Environmental Protection Agency and the U.S. Department of Energy's National Action Plan for Energy Efficiency. In addition, he is an advisory board member for the energy business leadership trade group Advanced Energy Economy, and a board member for the New England Clean Energy Council, as well as the efficiency start up FirstFuel.

Most recently Phil served the Commonwealth of Massachusetts as Undersecretary of Energy and as Commissioner of the Department of Energy Resources, the state agency with primary responsibility for fulfilling Governor Deval Patrick's vision for a clean energy future.

Prior to his service in the Patrick-Murray Administration, Phil was senior vice president and board member at EnerNOC, a start-up providing electricity demand-management services to businesses, institutions, utilities, and grid operators that became a public company in 2007. He was previously a senior partner and leader of Mercer Management Consulting's global energy utilities practice for 20 years. He started his career as a metals exploration geologist with Chevron and with Freeport-McMoRan.

Phil is also active in the nonprofit realm, having help found the Center for Effective Philanthropy and serving as Board Chair for 8 years as well as currently serving on the President's Council of ACCION. In addition, he completed full terms on the boards of the City Year Boston, First Parish Church of Wayland, and Haitian Health Foundation. He was also the founding chair of Boston Cares.

Phil is a geologist (B.S. from University of New Hampshire and M.S. in Economic Geology from the University of Arizona) and a management professional (M.B.A. from Tuck School of Business at Dartmouth)

Chairman WEBER. Thank you, Mr. Giudice. Dr. Whitacre, you're up.

TESTIMONY OF DR. JAY WHITACRE, CHIEF TECHNOLOGY OFFICER, AQUION ENERGY

Dr. WHITACRE. Mr. Chairman, members of the Committee, thank you for inviting me to speak today on the innovation and grid scale energy storage. I also want to acknowledge the Bipartisan Center's American Energy Innovation Council for working with your staff on setting up this important hearing.

I am the Founder and Chief Technology Officer of Aquion Energy. I am also still a Professor of Materials Science and Engineering, and Engineering Public Policy at Carnegie Mellon University.

Seven years ago, I set out to solve the problem of making large-scale energy storage systems that are high-performance, safe, sustainable, and cost-effective. The solution we developed is an Aqueous Hybrid Ion intercalation battery, which is a mouthful, I know, but it's simple. It uses a saltwater electrolyte, manganese oxide cathode, carbon composite anode, and synthetic cotton separator. We chose these materials because they are made from safe, cheap, and abundant elements which will make a technology cost of around $100 per kilowatt hour achievable when produced at scale. The battery performs remarkably well; providing long-duration discharges of up to 20 continuous hours, while maintaining performance over thousands of cycles and, thus, many years of operation.

We now have over 130 employees and a full-scale manufacturing facility in western Pennsylvania, as well as a satellite office in Boston. We have been shipping product to customers since mid-2014, and our batteries are now deployed or under testing with service provides in 18 States, who serve, in theory, millions of customers. Our products have also been exported overseas to Germany, Australia, Malaysia, the UK, and the Philippines, among other locations.

The story of Aquion is indicative of the kind of public-private partnership behind many game-changing energy technologies. The idea for Aquion's battery came out of my research at Carnegie Mellon, which was actually informed by my seven years working as a Senior Staff Scientist at NASA's Jet Propulsion Laboratory. Shortly after arriving at Carnegie Mellon, I started a small exploratory project on this sodium ion battery chemistry that resulted in some key early results. This allowed me to garner some seed funding from a venture capital firm that allowed me to incubate the concept at university for a year or so, until some critical performance goals were achieved in the lab. At that point, we decided to try and start a real company. At the same time, we applied for and received Department of Energy funding, which was matched by private investors. Set up the facility, focused on prototyping battery units, build a pilot-scale production line, and demonstrate performance in a grid-connected environment. Additionally, that funding supported continuing basic research at Carnegie Mellon; the results of which helped us refine the technology and our manufacturing processes at the company. After pilot production and demonstrating the performance of the technology, Aquion was able to raise multiple rounds of private investment that has allowed us to scale and commercialize our batteries.

Without this DOE partnership, our early days would have been far more challenging, and perhaps Aquion would not have made it this far. My decision to—back in 2008 to spin out the company was wrought with risk. Aquion had to cross that pre-revenue valley of death where we're spending a tremendous amount of money and time to turn lab results into something that was a bankable technology, while—at the same time, while the technology and the manufacturing piece is not well defined.

It is very challenging to find private investors who can stomach this much risk. A handful exist, but by themselves, it's rare for them to—to them to actually double-down and make it happen. And it's even more difficult to get—net new technologies like ours and Ambri's scale—to the scale that it's been done without this kind of support.

The partnership I had with DOE was critical for getting across this chasm, from a research concept to a marketable product with proven performance. Furthermore, we continue to collaborate with the DOE. We're actively testing various generations of our products, and have partnered with us to develop large, in-house energy storage test beds.

What can be done by the DOE and national labs to advance other breakthroughs? The DOE has a solid track record of encouraging good ideas and funding projects that can result in a significant impact. However, one key aspect that is often overlooked early in the technology development process is the difficulty of scaling and manufacturing. Since all new energy technologies will be both materials and manufacturing-intensive, focusing more on these aspects of the process early on would increase the success rate of translating lab results into market products. There is still a tremendous amount of important and interesting fundamental science and engineering to be done during the process scale-up and manufacturing side of any new energy storage technology. I would, therefore, encourage the DOE and the national labs to incorporate the considerations of scalability early in the technology development process, such that they are focused not only on what benchtop solutions make sense, but also how to turn a benchtop solution into a scaled, mass-produced and relevant technology.

Thank you for the opportunity to share Aquion's story, and the attention you are devoting to energy technology and development.

[The prepared statement of Dr. Whitacre follows:]

Testimony of Jay Whitacre
Chief Technology Officer, Aquion Energy
HOUSE SCIENCE COMMITTEE HEARING:
"INNOVATION IN BATTERY STORAGE FOR RENEWABLE ENERGY"

Mr. Chairman and members of the Committee, thank you for inviting me to speak today on innovation in grid-scale energy storage. I also want to acknowledge the Bipartisan Policy Center's American Energy Innovation Council for working with your staff on setting up this hearing.

My name is Jay Whitacre, and I am the Founder and Chief Technology Officer of Aquion Energy. I am also a Professor of Materials Science & Engineering at Carnegie Mellon University.

About Aquion

At Aquion Energy, I set out to solve the problem of making large-scale energy storage systems that are high performance, safe, sustainable, and cost-effective. The solution we developed is an Aqueous Hybrid Ion intercalation battery, which uses a saltwater electrolyte, manganese oxide cathode, carbon composite anode, and synthetic cotton separator. It's safe and sustainable—the water-based chemistry results in a nontoxic and non-combustible product that is safe to handle and environmentally friendly. It performs remarkably well—providing long-duration discharge of up to 20 continuous hours while maintaining performance over thousands of cycles, and thus many years of operation. The system is modular and can be scaled to right-size applications. And the system is tolerant to abuse and requires no thermal management or regular maintenance.

Aquion's batteries are thus suited for long-duration, daily cycling applications. In addition to enabling the integration of variable generation from renewable power sources, Aquion's batteries provide back-up and off-grid power, grid reliability services, and load-shifting for customers wishing to avoid peak electricity rates or demand charges.

Aquion is currently manufacturing a completely novel product that is shipping to paying customers after being produced in a factory established in a refurbished automobile factory about 35 miles east of Pittsburgh. To date, Aquion has created over

150 full-time jobs and lured numerous highly trained individuals and families to the Pittsburgh region. In mid-2014, the first generation of the Aquion AHI technology was commercially launched and global sales have been increasing since then. Multiple megawatt hours of energy storage have been produced at Aquion's factory and shipped all over the world.

Aquion's batteries are being installed in (among other places) Australia, Malaysia, the Philippines, Germany, Hawaii, and California. An additional compelling aspect of this market (that is projected to grow into a multi-billion dollar industry in the next 5 years) is that the use cases and locations will provide excellent data as the technology continues to mature and cost down to the point where it is relevant for large-scale grid-tied installations. As such, Aquion is taking a classical approach to cultivating a disruptive technology: identify or create a smaller market (distributed PV solar/battery hybrid systems in this case) that has characteristics of the larger desired market and dominate that smaller market while selling at lower volumes and higher price points.

The Beginning

I initially developed the concept for Aquion's battery technology when I arrived at Carnegie Mellon University (CMU). My previous position was that of Senior Staff Scientist at NASA's Jet Propulsion Laboratory (JPL), where I learned a tremendous amount not only about functional materials for energy technologies, but also about systems engineering and risk assessment. When I arrived at CMU, I set out to apply my knowledge, largely gained while working for seven years at one of the premier national lab environments in the world, to solve a key and pressing problem. I asked the question: "What is most needed in the world that I could potentially contribute to such that it will result in near-term impact?" After several months of surveying the landscape of "energy devices that rely on electrochemically functional materials," I concluded that the technology most lagging behind market needs was stationary energy storage for use in applications ranging from distributed microgrids in developing countries to large scale grid-tied installations around the world.

With the knowledge that a strong economic underpinning is required of any successful energy technology, I first performed a basic techno-economic analysis to arrive at the key metrics that would then inform any experimental work. For stationary energy storage, energy density requirements can be set aside, and so the primary metrics become specific cost in $/kWh. Specifically, for stationary storage to be economically viable, the capital cost of the storage itself should be less than $200/kWh and should approach $100/kWh to be truly disruptive. A simple analysis suggests that as the cost of the materials increase, it is very difficult to approach the cost goals without having exceedingly high energy density. The challenge at hand when considering existing technologies was then evident: only a handful of battery chemistries have specific energy values in excess of 100 Wh/kg at the device level. Any storage technology that has a specific energy <100 Wh/kg must have a total mass-normalized cost of goods sold (COGS) of less than $10/kg to meet the $100/kWh target. This specific cost value is substantially lower than the well-documented mass-averaged COGS for nearly every battery system. With this in mind, I set out to survey all possible materials sources and related processes to identify what, if any, materials might be low cost enough to enable the technology we sought to develop. While this preliminary process did not directly result in any specific inventions, it was critical to informing the innovation path that followed. Without it, my work would not have been able to so directly respond to a key global technological hole. As result of my training at JPL as a systems engineer, I recognized that technological and economic context are paramount, and that any innovation or invention can have little meaning or impact without it.

After a deep survey on relevant academic and intellectual property literature on similar fields yielded some compelling directions, I decided that the most appealing electrolyte system would be sodium-ion based and have a neutral pH aqueous electrolyte. Sodium is chemically similar to lithium, but is ubiquitous and extremely inexpensive. The next step was to identify or create electrode materials that could reversibly interact with sodium ions in an aqueous electrolyte in a similar fashion as observed in Li-ion batteries, a process known as intercalation or insertion reactions. At that time, no one had investigated or reported a sodium-ion intercalation battery electrode material that was stable in an aqueous electrolyte. After a significant amount of materials screening, the first of several key electrode materials were identified and proven; the little-explored solid-state ceramic material $Na_4Mn_9O_{18}$. Not only was it demonstrated to be functional and stable, this particular phase of sodium manganite could be made by mixing two extremely inexpensive precursors and heating them in air: electrolytic manganese dioxide and sodium carbonate (or sodium bicarbonate), for a total potential materials cost of under $2/kg. This result was documented and protected in a provisional patent application in the spring of 2008 and as I continued my search for other similarly functional materials, I started to engage potential sources of funding, and was successful in securing a seed-round investment from a prominent venture capital to conduct technology incubation in his lab at CMU. This somewhat unusual arrangement is a testament to the promise and strength of the preliminary results as well as the promise that the technology holds.

Top-tier venture firms invest only in ideas or companies that are capable of having transformational impact, and once they commit, they seek to provide their company founders with as much support as possible. During the incubation phase (June 2008 to late 2009), nearly everything changed; several more sodium-compatible intercalation compounds were discovered and a range of device configurations were screened. The proof-of-concept device that was tested by a third-party lab in late 2009 was found to have excellent stability and very low materials and processing costs; the company was ready to spin out of the university.

At the same time, we applied for and received funding from the Department of Energy (DOE), which was matched by private investors, to prototype battery units, build a pilot-scale production line, and demonstrate performance in a grid-connected environment. Additionally, that funding supported continuing basic research at CMU, the results of which helped us refine the technology at Aquion.

In the following 4 years, the chemistry and the device changed substantially beyond the design proven at CMU. The novel battery chemistry is now known as the "aqueous hybrid ion" or "AHI" system, a moniker based on the fact that multiple functional ions (Na+, Li+, and H+) work in a hybrid fashion in the electrodes and electrolyte to participate in the energy storage reactions. The AHI chemistry uses ultra-low cost manganese dioxide based cathode material and anode comprised of both $NaTi_2(PO_4)_3$ ("NTP", which is made from pigment-grate TiO_2 and common chemicals used by the fertilizer industry) and high surface area activated carbons. One key recent development in the AHI chemistry was the discovery that the NTP anode material can be stabilized for long term use by the addition of other kinds of carbons that are in intimate local contact within the electrode. These carbons can serve to mediate the local pH conditions and stymie degradation reactions that can occur on the surface of the NTP. This concept is at the core of my most recent granted US patent.

Ten additional patents were issued around the world; all aspects of this new technology are novel and are protected, from the fundamental chemistry to the packaging design. This process established Aquion as a leader in next generation stationary energy storage technology field, and of the 10 to 15 new North American battery companies attempting to transition into full-scale manufacturing, only Aquion has succeeded. Data from batteries and systems deployed around the world show that the technology is highly functional and is able to deliver the services desired by the various customers. In 2015, several multi-MWh installations will be integrated in the Philippines, Hawaii, and Florida. See, for example, Aquion's recent announcement of a planned deployment in Hawaii: http://globenewswire.com/news-release/2015/01/07/695641/10114491/en/Aquion-Energy-Enters-Agreement-for-Major-Microgrid-Battery-System-Deployment-at-Bakken-Hale-in-Hawaii.html.

These early large-scale installations are a critical stepping-stone for Aquion, since the effectiveness and versatility of the technology as proven in these kinds of use cases will make our products more marketable.

Academic Openness

A cornerstone of Aquion's technology development and product communication efforts has been one of intellectual and academic openness. My staff and I have published many papers in the peer review literature that describe both the fundamentals behind the technology as well as product and systems-level performance. This openness has created international academic interest in the AHI technology and has encouraged others to investigate similar approaches and materials systems. While this might be seen as encouraging competition, the synergy that comes from sharing ideas and results is very beneficial to the company and outweighs the risk of creating competitive threats. Furthermore, this openly available information has allowed the AHI chemistry to gain marketplace credibility more rapidly, since the technical community consumes, scrutinizes, and accepts the results that are put forward.

Marketability

One key market-creating technical attribute of the AHI technology is the product's extraordinary robustness; in the early days of this project, we demonstrated that the materials could be charged/discharged over 5,000 times without losing function; this attribute has been a cornerstone of the AHI value proposition, since being able to promise over 10 years of daily cycles without requiring significant recharging is extremely attractive to all markets and allows them to compete favorably against most other technologies (especially those with a similar price per kWh).

Another key marketable attribute of the AHI technology is its environmental benignness. Unlike any other productized battery chemistries, the AHI battery has no environmentally toxic or hazardous materials, and the environmental impact of the manufacturing process is also extremely low. The units consist of recyclable polypropylene external packaging, saltwater electrolyte, inert ceramic powder active materials, carbons, and stainless steel fixtures. This single attribute of the technology is extremely appealing to some customers/markets, since there is a growing worldwide movement to incorporate and use cleaner and environmentally certified technologies, especially amongst leading corporations. The Aquion product line has received a full cradle-to-cradle audit/certification by the McDonough Braungart Design Chemistry Corporation, who have a widely accepted Cradle-to-Cradle (C2C) certification process. Aquion can now successfully market the first and only C2C certified battery chemistry. Specific customers who are interested in this certification include European ventures in reaction to the movement to remove lead from the consumer use stream, and also developing countries who have poor or even no recycling programs to deal with the normally very hazardous battery technologies commonly used (with lead acid being the biggest concern).

Next Steps

As Aquion continues to scale, we will be exploring the distribution of our manufacturing infrastructure such that active materials production is co-located with low-cost materials sources and potential customer bases. This includes the exploration of setting up operations in Asia, South America, Australia, and South Africa. The materials-intensive nature of the product combined with the ease of manufacturing results in a very significant opportunity to create not only a worldwide customer base, but also a worldwide materials-centric production base where the economies of scale and transport can be optimized to an extraordinary effect. Specifically, at full global scale with the appropriate manufacturing assets installed at optimal locations, it is very possible that the Aquion energy storage system can be produced and sold at or below $100/kWh, which is a common "holy grail" price point that is often discussed as a figure that would disrupt the global electricity market because it can legitimately alter the way large format power systems are designed and implemented. If Aquion continues on our current commercialization/growth trajectory, it is estimated that we will be able to achieve this price/performance point sometime in the 2017/2018 timeframe which is close enough to interest key technology partners such as major US utilities and international energy companies: Shell, Total, Exelon, and multiple other North American utilities who are currently all partners and/or investors.

Societal impact of the technology

If the technology envisioned manifests as planned, the way the world (not just North America) uses electricity will be positively impacted. Specifically, scalable, inexpensive bulk storage of electricity provides: (1) a mechanism for integrating large quantities of wind and solar generation, (2) a way to remove peak demands for generation and increase the trough electricity demands to make generation demands more constant, thus better utilizing traditional power generation assets, (3) a method for increasing system reliability, and (4) through each of these actions, lower the cost of providing electricity.

Renewable energy technologies are in a delicately balanced situation currently; anything that can further increase the credibility and positive perception of this new technology is still badly needed. There is a core audience who has accepted that energy storage is the inevitable wave of the future and is necessary to decrease mankind's global carbon footprint. However, more recognition and media focus is needed to inspire the next generation of innovators as well as help current technologies mature to the point where they are able to reach their true potential.

Without the partnership with DOE, it would have been far more challenging, if not impossible to move out of the lab and into the market—and perhaps Aquion would not have made it this far. My decision back in 2007 to spin out a company had a lot of risks. I had to cross that "valley of death" when you have no revenue, you're spending a lot of money and time to turn your lab results into a working commercial energy technology (and the manufacturing process to make it), and that technology's ultimate performance is uncertain. It's challenging to find private investors who can stomach that risk-reward profile—a handful exist, but by themselves it's rarely enough to get new capital-intensive technologies done. The partnership I had with DOE was critical for getting across the "valley of death," from a research concept to a prototype battery and manufacturing process with proven performance. Specifically, without DOE investment, we would not have had enough patient capital to take us through prototype production. This is an excellent example of how having key funds at the proper moment can boost a project significantly. Furthermore, we continue to collaborate with the DOE, who are actively testing various generations of our products and who also have partnered with us to develop a large in-house test bed. This support is important to us as we build technical credibility and continue to refine our product offering.

What can be done by DoE/National labs to advance other breakthroughs? In some ways, the DoE has a solid track record of encouraging good ideas and funding projects that can result in significant impact. However, one key item that is often overlooked early on in the technology development process is the difficultly of scaling/manufacturing. Since all new energy technologies will be both materials and manufacturing intensive, having more focus on these aspects of the process would increase the success rate of translating lab results into market products. There is still a tremendous amount of important and interesting fundamental science and engineering to be done in the process scale-up and manufacturing side of any company that is developing a new solution. I would encourage the DoE/national labs to further recognize this importance and to work to insert the realities of scaled manufacturing early into the technology development process such that national labs and DoE are assets focused not only on *what* bench top solutions to make, but also on *how* to turn a bench top solution into a scaled, mass-produced and relevant technology.

Thank you for the opportunity to share Aquion's story with you, and the attention you are devoting to energy storage technology development.

Biography of Jay Whitacre
Chief Technology Officer, Aquion Energy

Dr. Jay Whitacre was raised in Westerville, Ohio, and from a young age was technically inclined: he was an avid computer programming by age 9 (in 1981), scored a near perfect 39/40 at the Ohio State Science Fair at age 12, and won various awards in high school for achievements in Science and Engineering. He attended Oberlin College, where he graduated in 1994 with Honors in Physics and a Minor in Philosophy. While at Oberlin, he completed a year-long independent research project studying thin film solid-state PV solar cells – an experience that cemented his lifelong interest in clean energy technologies. He earned his Masters (1997) and Ph.D. (1999) in Materials Science and Engineering from the University of Michigan where he continued his work on thin-film solid state materials and devices, spending a significant amount time performing research at the Stanford Synchrotron Radiation Laboratory, where he used high resolution x-ray scattering techniques to characterize thin film interface and surface properties.

Whitacre parlayed this work into a Postdoctoral Scholar position at Caltech to study and develop thin film solid-state electrochemically functional materials and devices (in collaboration with researchers at the Jet Propulsion Laboratory). A year later, he was hired as a full time member of the technical staff at JPL and spent the next 6 years exploring a wide array of functional materials, devices, and systems for power/energy applications. Early successes included the discovery of a low-temperature processing route for producing highly functional crystallographically oriented electrode structures. The paper describing this work won Whitacre the Electrochemical Society's Norman Hackerman Young Author award (judged to be the best paper published in the Journal of the Electrochemical Society by an author under 30). An extension of the results described in this paper led to several patents and the creation of the smallest "on-chip" solid-state Li-ion batteries and battery arrays ever produced.

As Whitacre became more accomplished in the field of electrochemically functional materials, he expanded his research to cover fuel cell catalysis, nanostructured electrode powders for Li-ion batteries, thermoelectric materials, large format batteries for aerospace applications, and high capacity fluorinated carbon electrode materials. At age 32, he was promoted to the "Senior" Level at JPL and was trained as a power systems engineer by the in-house concurrent engineering design team known as Team X. This experience greatly expanded his appreciation for the technology selection and implementation process and also galvanized his desire to focus on energy-related research topics that can have a significant impact at the systems level. While at JPL, Whitacre was the primary author of 3 US patents, over 10 provisional patents, Author or Co-Author on 25 Peer-Review Publications, and was listed as an inventor on 12 new technology/invention disclosures (that were published in "NASA Tech Briefs"). He won 3 NASA Space Act awards (2002 – 2004) for innovation and invention. In 2005, Whitacre was chosen to be the Cognizant Engineer for the Mars Science Laboratory Decent Stage energy storage sub-system, a task that included oversight, design, and the early stages of implementation of a thermal battery-based system that flawlessly powered the critical 20-minute Entry Decent and Landing phase of Curiosity's mission in August 2012.

In 2007, Dr. Whitacre accepted a joint appointment at Carnegie Mellon University in the departments of Materials Science & Engineering and Engineering & Public Policy. Since then, he has established himself as an international leader in the field of large-scale energy storage devices and systems (for vehicles as well as stationary applications) by examining key problems from both fundamental materials as well as systems/economic/policy perspectives. He has developed a broad research group where lab work is conducted in concert with policy techno-economic analyses to justify work and assess the impact of various results.

Whitacre's technology policy-related projects include a study of the performance of Li-ion batteries as used in urban driving environments, with an emphasis on understanding the economics of performance degradation in the context of battery pack sizing and pricing decisions. His Materials Science research has been focused on understanding and exploiting functional ceramics and metallic alloys for energy storage and conversion. Generally speaking, his is focused not on a collection or classification of material types (as is academically traditional in the MSE field), and instead is more inclined towards a family of physical phenomena and engineering principles related by functionality, application, and policy.

Whitacre's research into ultra low cost neutral pH aqueous electrolyte energy storage functional materials and devices, which started in 2007, has led to 7 granted United States Patents, multiple granted international patents, with more than 20 more applications under various stages of examination. The novelty and potential impact of this work allowed Whitacre to raise significant funding from the venture capital community, starting with an investment from Kleiner Perkins Caulfield and Byers in 2008, that led to the founding of a company initially named "44Tech". The company spun out of CMU in January 2010 as Aquion Energy, and has been growing rapidly ever since. From June 2008 to April 2011 Aquion did not have a full-time CEO; as such, Whitacre (as Founder and CTO), was the highest-ranking company officer and was largely responsible for successfully shepherding the technology first demonstrated in his labs through the early phases of development to the point where scaled manufacturing of a product was considered viable. During these years, Whitacre took multiple semesters of leave without pay from Carnegie Mellon while still maintaining his research group there.

He is an unusually interdisciplinary researcher with demonstrated strengths in different but related disciplines, and as such is at the forefront of the "sustainable energy technology" field. Communicating with academic, policy, and industrial communities has involved invitations to speak at venues ranging from technical conferences (including keynote addresses and invited presentations at Gordon Research Conferences), to delivering a TEDx talk, to speaking at the Aspen Institute Summer Ideas Festival (2013), the Toyota Sustainability Conference (2011), and Harvard Business School (an HBS case study on Aquion Energy was written in 2011 and is taught frequently). Whitacre has won numerous awards, including a CMU early achievement award (2009), the endowed Elia Development Chair (2010), and also recently won the 2014 Carnegie Science Award for Advanced Materials, and the 2014 Resnick Institute "Resonate" award for Achievement in Sustainability Sciences. In May of 2014, Fortune Magazine listed Whitacre as one of the top 25 Eco Innovators in the world (#19), along with Elon Musk, James Cameron, and the founders/CEO's of various large global energy technology companies (http://fortune.com/2014/05/01/the-worlds-top-25-eco-innovators/). Aquion Energy has also won many awards and has been listed in the MIT Technology Review's annual "50 Most Innovative Companies" in both 2013 and 2014. Beyond these high-profile honors, multiple other awards have been bestowed on both Whitacre and Aquion. Along with receiving funding from Bill Gates ($10 Million in 2013), Whitacre was also selected to sit on an small energy advisory committee, which culminated in a 6-person round table day-long sessions with Mr. Gates in 2014.

Chairman WEBER. Thank you, Dr. Whitacre.

Did we lose Chairman Smith? Okay. So I will recognize myself for five minutes, and start with some interesting questions.

Dr. Gyuk, the Fiscal Year 2016 budget request includes a proliferation of battery and energy storage R&D scattered throughout DOE, including in the Office of Science, through the Joint Center for Energy Storage Research, JCESR. Do you all have a name for that, an acronym? JCESR, okay. Which, to me, sounds like some kind of salad dressing, but—in ARPA–E, in the Vehicle Technologies Program, the Solar Energy Program, the Hydropower Program, the Geothermal Program, and Advanced Manufacturing Programs at EERE, and then the program you manage, the Energy Storage Program in the Office of Electricity. So how does the department make sure the highest priority research is funded, and how do you avoid duplicative research?

Dr. GYUK. Thank you for this question, Mr. Chairman. It's a very complex question, and I will try to attempt answering at least part of it.

I would like to point out first of all that our particular program in the Office of Electricity is the first and original program at the Department of Energy. Most of the other programs entered the fray when grid storage reached a certain stage of development. ARPA–E does very interesting research aimed at cutting-edge technology. They are in the form of grants, and they have produced some very interesting projects like the Ambri project that we have heard about. We also interact with them. In fact, I was the person who suggested to the head of ARPA–E that he ought to be interested in grid energy storage.

The Office of Science does basic work on—mostly on the electrochemistry involved in storage; catalysis and things of that type. We don't do hydropower because there is an office, and hydropower is a well-developed technology which has some interesting things if you—to advance, but it's not in the purview of our particular office.

Chairman WEBER. Let me break in here for a second. Do you have a particular person who's tasked with watching these different programs, assessing their priority, and determining what's the highest level, and if so, who is that?

Dr. GYUK. I believe not, however, we are putting together the QER Program which will provide more of a framework for not only grid energy storage, but also the whole field of grid-related energy projects.

Chairman WEBER. Okay. Well, forgive me, we're running short on time. Do you believe that grid-scale energy storage research receives the same priority within the department as vehicle battery R&D? Grid-storage research same priority as vehicle battery R&D.

Dr. GYUK. Battery storage for vehicles has been sponsored for a long time, and has produced some very good results on lithium ion, and it's also at a much higher budget level than——

Chairman WEBER. Well, when I—when we look at the numbers in the budget request, I have to tell you that grid-scale research looks to be a lower priority, just from the numbers in the budget request.

Dr. GYUK. I would prefer to call—to say that we have a lower budget, but it's not necessarily lower priority.

Chairman WEBER. So—and that was my first question; who's assessing those priorities. But let me move on to my third question for you. Wouldn't it make sense to cut the overhead cost and risk of duplication by combining all of these various programs into one battery and one energy storage program at DOE? If yes, why—if no, why not?

Dr. GYUK. I would have to do this on a personal basis because policy decisions of that type are generally made by people in the administrative offices.

Chairman WEBER. Okay. All right, well, I'm going to move on. All witnesses, very quickly. What impact could large-scale energy storage have on electricity reliability and reducing cost for customers? I mean that's our goal, right? So just as quickly as you can, what impact could large-scale energy storage have on electricity reliability and reducing the cost for our consumers? Doctor, we'll start back with—actually, let's do it backwards. Doctor, let's start over on this end.

Dr. WHITACRE. The impact ranges dramatically depending on location, and depending on what kind of infrastructure and what kind of degree of renewables are local. In some places it can have a profound effect, and others it can be less profound. The message really is we need to figure out what locations can benefit most from grid-scale storage and implement those first, and then let it trickle through.

As Phil indicated, one of the key things to do is to first try and off-set these peaker plants that are very rarely turned on. That's a low-hanging fruit. Also finding places where we can level out wind or solar. Low-hanging fruit. And from there, there are weak points in the grid that are also low-hanging fruits. So you phase this in at the biggest pain points first and move through. It's hard to put a dollar value on it, but there are already significant pain points.

Chairman WEBER. Could you put a percentage on it?

Dr. WHITACRE. Not for the entire country. For different locations you can. It's a hard question to sort of average out because it's a time question and a location question. I will defer.

Chairman WEBER. Okay.

Mr. GIUDICE. Yeah, just quickly, I agree completely with Dr. Whitacre. The—it is very situationally-specific, especially over these next few years. When proven out over this next decade and more, I think we could be at an electric system that could cost us 30 to 40 percent less than our existing electric system——

Chairman WEBER. Less.

Mr. GIUDICE. —and largely because less assets will be involved. Right now, this is the most capital-intensive industry in the world. It's $3 of assets for every $1 of revenue that the industry generates across the entire value chain, and that's all because we're not using these assets very much. A lot of assets are laying idle in preparation for when we have our peak demand. So with storage fully developed and fully deployed, I think it could be a very, very different——

Chairman WEBER. Well, I love hearing the 20 to 30 percent lower, but it just depends on what the investment is. Dr. Virden?

Dr. VIRDEN. Well, thank you for the question. I like one part of your question a lot, which is the goal of energy storage is to keep prices down.

Chairman WEBER. Yeah.

Dr. VIRDEN. It'll serve certain very high-end markets initially, but the goal is to keep prices down. And it will have a huge impact on resiliency and reliability and robustness of the grid.

Let me give you one example. We did an analysis for Puget Sound Energy, and they had three substations that were basically maxed out at capacity about 9 days out of the year. Texas has the same challenges in the middle of the summer. And they asked where would energy storage have the biggest impact into maintaining the reliability of that substation and the distribution feeder. We did the analysis. It turns out you could put about a 3 megawatt battery that would run for 3 to 4 hours at a certain substation. Now, the key was they gave us real world data so we could make that analysis. It saved them, given the ROI they wanted, $6 million over the other options which were upgrading the transmission infrastructure, the distribution infrastructure, the substation. So with that battery, they can now meet, they believe, 90 percent of the challenges they have on that distribution feeder. And the main return on investments for them was inter-hour balancing, so balancing on that distribution feeder the, you know, inter-hour requirements. T&D deferral was the next one. And we often talk about renewables, but the arbitrage part of that had very little ROI, even though the battery would spend 15 percent of the time. So as the previous witnesses said, there's no one answer fits all. You almost have to go utility-by-utility and what their specific needs are, almost down to the distribution level.

Chairman WEBER. Dr. Gyuk, I'll let you weigh-in on that quickly please.

Dr. GYUK. It's easy because most of the points I would like to make have just been covered.

Chairman WEBER. Okay.

Dr. GYUK. I think we are all agreed that we have to start things slowly, and where we can find the most sensible results. Frequency regulation is already cost-effective in at least Texas and the FERC areas. Resiliency and emergency preparedness is an important one because when you need it, any price is good, and that includes the military bases. So military bases, islands, coastal areas are beautiful for resiliency. Peaking is another one. But the whole thing is about getting the right benefit streams, and increasing the asset utilization of the system as a whole.

Chairman WEBER. Okay, thank you very much.

And at this time, I'm going to yield to the Ranking Member.

Mr. GRAYSON. Thank you, Mr. Chair.

Intel spends $5 billion a year on research and development. There are several drug companies that actually match that or exceed it. Why don't we see the same thing with regard to batteries? Batteries are over $100 billion a year in revenue, why don't we see Eveready or Duracell or Rayovac doing the same kind of research that would, to a large degree, underwrite what you do every day? I think Dr. Whitacre alluded to that in his testimony, so I'll start over there.

Dr. WHITACRE. Yeah, there was actually a very interesting—thank you very much. There was a very interesting report done by the DOE, perhaps almost ten years ago now, that assessed this, and one of the findings was that, early on, I think folks recognized—this is for lithium ion batteries specifically, that in North America the return on investment on this kind of technology is a very long—it's a very long investment window. Japan and other folks in Asia were more willing to invest over that long period of time, compared to what you might find in North America. So there was a general perception that this is a long-haul kind of technology development process, and that, in some cases, I think it's very difficult for North American and North American industry to double-down on a very capital-intensive, very costly situation.

Mr. GRAYSON. Mr. Giudice, go ahead.

Mr. GIUDICE. Yeah, so to address the question, this is not unique to batteries. This is the—one of the energy challenges that the energy industry faces, especially the electricity industry, and it's part of the nature of the industry structure. There was an organization, the Electric Power Research Institute, that was—that came together to try and spur R&D and demonstration projects. It's a very small budget. The vendors are—have a very small budget. The industry is not set to innovate in general, and so it's a—there isn't a model in this industry, writ large, not just around batteries, to innovate and to invest in the kinds of ideas that could be breakthrough. And it's in part related to the nature of this industry. It's a highly regulated industry, both federal and state. It's not an industry that goes easily into change. When you have this kind of asset intensity, we have 30-year lifelong assets that they're dealing with, so they're not sort of with the mindset of let's keep reinventing ourselves every couple of years. And so I think that it really suggests why there's such an important federal and other public policy roles to bring us to a better energy future.

Mr. GRAYSON. So are you suggesting that it's economic or that it is regulatory, or that it's cultural, what do you think is the most important——

Mr. GIUDICE. I think the fundamental economics are not—do not reward innovation at this stage, and consequently, the regulations are not such that they're spurring change across the board. And it relates to smart metering, it relates to all kinds of aspects of the electric industry. It's not just as it relates to storage. Yeah.

Mr. GRAYSON. Doctor? Doctor Virden.

Dr. GYUK. Yeah. Well, first of all I'd like to point out that there are battery companies that are working on innovation. For example, a company in Pennsylvania called East Penn worked with us to develop the ultra-battery which has a cycle life which is almost 10 times that of a regular lead acid battery. General Electric is another company that actively works on research. But I agree with you that by and large, the battery industry is conservative. And the utility industry is conservative also, although we do have forward-looking utilities like Southern California Edison, Florida Power and Light, First Energy American Public—you know, and various other companies of that type. But the federal impetus, I think, is helpful in bringing out the best in these companies, and coaxing them towards innovation and new battery development.

Mr. GRAYSON. Dr. Virden?

Dr. VIRDEN. Yeah, with the Intel example specifically, they've got about an 18-month R&D cycle for next products, and huge profit margins. And when you start wandering into the grid and the energy storage space, the fundamentals, and I think you said it here are it's high capital, high risk, long-term payback, and fragmented market, and it makes for uncertainty.

Mr. GRAYSON. All right, I see I'm almost out of time, so I yield back.

Chairman WEBER. I thank the gentleman.

Mr. GRAYSON. I'm sorry. I'm sorry, Mr. Chairman. I have one more question.

Chairman WEBER. The gentleman is recognized.

Mr. GRAYSON. Thank you.

Doctor, I'd like you to try to clarify your response to Chairman Weber's question earlier about who coordinates the various energy storage activities at DOE. Is it true that the Secretary established the Undersecretary for Science and Energy for that purpose?

Dr. GYUK. Yes, that is true.

Mr. GRAYSON. All right, thank you.

Dr. GYUK. Yeah.

Mr. GRAYSON. Now I yield back. Thank you, Mr. Chair.

Chairman WEBER. And now the gentleman that drives a battery just about everywhere he goes is recognized. Gentleman from Kentucky.

Mr. MASSIE. Thank you, Mr. Chairman. I drove an 85 kilowatt hour battery here this morning. It has four wheels. And that's probably the way to look at it; it's a rolling battery.

Before I ask some questions about batteries, I want to ask Dr. Whitacre and Mr. Giudice about the role that patents play in commercializing technology. I think this is something that a lot of my colleagues here in Congress don't fully appreciate why these are in our Constitution, but can you tell me do patents help or hinder you in your quest to commercialize this technology?

Dr. WHITACRE. Thank you. I believe that maintaining a strong intellectual property stable, both patents as well as trade secrets, is critical. Folks will not invest or really take heart that you have something that's legitimate unless you have some documentation that establishes your right to, you know, exercise your idea without being copied immediately. So it's critical. And that story really matters.

On the other hand, I will say especially in the energy technology space in general, and batteries specifically, there is a tremendous amount of overlapping intellectual property right now that is difficult to assess out, and there has been a lot of really interesting court cases and a lot of other things that go with this. Chemistry materials are hard to patent and maintain patent. And there's a difference between right to practice, versus right to block.

So it's critical—I am positive that we wouldn't have got the degree of investment that we have gotten without the nine or ten patents that we have, and the worldwide patents that we have as well. It's super important.

Mr. MASSIE. Thank you.

Dr. WHITACRE. On the other hand, you know, it doesn't hurt us, for sure.

Mr. MASSIE. Right. Let me give Mr. Giudice a chance to——

Mr. GIUDICE. Sure. I share the—Dr. Whitacre's perspectives on this as well as far as the patents are critical. Intellectual property, without having our control of our intellectual property, we would not have attracted the investors we have. They are all motivated for long-term significant positive change for the planet and the country, but the financial rewards are what enables them to be able to write the checks for us. So I don't think that there's any doubt in my mind that without that, it would—it would not have been the same kind of conversation.

Mr. MASSIE. Thank you. That confirms what my experience, when I started a company at MIT with technology from there is that, without patents—and you might think you would want all this to be shareware, but the reality is the investors will not come and invest the money and commercialize in the manufacturing unless you have patents. And you have to be able to defend them as well. And I know it can get messy with overlapping technology, but that's what the courts are for, and we can get to the facts.

So now, I'm sort of on a mission here in Congress to protect our intellectual property system, and it's—trust me, it's being attacked here right now. Quick—have a few questions. What—Dr. Gyuk, what portion of our storage capacity right now consists of pumped hydroelectric capacity on the grid, just roughly? It seems to be the most conventional at this point.

Dr. GYUK. It's the vast majority. Pumped hydro is a classical technologies—technology. All the utilities that have it bless the day when it was put in because it helps them with peaking power. I mean it's very difficult to live without it.

Nonetheless, not very much is being built these days.

Mr. MASSIE. Why is that?

Dr. GYUK. It's a combination of most—many of these plants were built to cope with the hoped-for development of nuclear power, because nuclear power likes to put out flat electricity, and the pumped hydro was intended to follow the load and do the up-and-down. Since nuclear power is not as big a component of our national energy budget as was intended, the impetus for doing pumped hydro is less.

Mr. MASSIE. Thank you.

Dr. GYUK. It's also very expensive to build a new pumped hydro plant.

Mr. MASSIE. Is—and how does it compare like with batteries right now, the cost of pumped hydro versus, say, a chemical solution?

Dr. GYUK. When you take into account a long lifecycle, a pumped hydro could run for 20, 30 years easily. You amortize over that period and the cost—the lifecycle cost them becomes lower than most batteries. And that's sort of what we have to crack with battery research. The same is also true for compressed air energy storage, of which we have two very good examples in the world; one of them in Alabama in Huntsville, and the other one in Germany. But we are now developing new compressed air energy storage. That's another bulk technology that amortizes over long periods of time, and will give us good output.

Mr. MASSIE. Thank you very much.

I see my time has expired. Are we going to do another round of questions, hopefully? I'll beg for some more time if——

Mr. GRAYSON. I don't have any objection to that.

Mr. MASSIE. Okay. I yield back then.

Chairman WEBER. The gentleman yields back.

The gentleman from California is recognized. Or—I'm—yeah, that's right. Go ahead, Mark.

Mr. TAKANO. Yeah. Thank you, Mr. Chairman. I also appreciate the Subcommittee's indulgence to allow me to join today. Mr. Chairman, I appreciate the opportunity.

Mr. Giudice, last week the majority passed a bill out of our Committee that would have cut—that did cut funding for ARPA–E by 50 percent. In contrast, your testimony strongly recommends increasing our support for the agency, and provides an excellent example of the critical role that ARPA–E now plays in advancing new grid-scale energy storage technologies. Can you explain why you believe that ARPA–E is such an important part of our nation's energy innovation ecosystem?

Mr. GIUDICE. Thank you for the question. Yes, ARPA–E is a relatively new agency, and it has done a remarkable job in the few short years that it has been up and running and operating. I do think that, as we were talking earlier, I think Ranking Member Grayson mentioned the comparison of Japanese spending on storage, $670 million a year, versus the budget that Imre Gyuk controls of $12 million a year. ARPA–E fills a little bit of that gap, and it's—their mission, obviously, is much broader than just energy storage, but they are there to try and help create the breakthroughs that will serve our country and our planet for years and years to come. There is no alternative to that. There isn't a private sector group that's going to stand in to do that, there's not private investors through the venture capital-type community that can stand up and take the lead on these kinds of innovations. The large corporations are spending very small amounts of money because it's not economically attractive to them to do that. So there is no one else to be able to take on that leadership. I strong encourage the continued support for the ARPA–E Program.

Mr. TAKANO. Would your company and your technology be anywhere near where it is today without the early stage investments from ARPA–E? Would it even exist?

Mr. GIUDICE. I do not believe it would exist. I don't believe that— and to be clear, it was the campus research that got funded at MIT, so it was all done under a public-private—or public partnership with the ARPA–E on that. And that was necessary to advance the technology to the point that we could attract and have conversation with private investors. So we weren't even ready for any kind of conversation with private investors when it was just a concept. That was necessary to prove out in the laboratories at MIT before it could be at all of interest to private investors.

Mr. TAKANO. So we see that—we know that you have a number of private investors, notable ones, and you're saying to me that the private sector could not have done this just on its own.

Mr. GIUDICE. I'm saying they could, but they would not because there is no economic package that makes sense on the—on its own.

Mr. TAKANO. So—I mean in theory, it's possible that they could have—they have the capacity——

Mr. GIUDICE. That's right.

Mr. TAKANO. They have the capacity to do this.

Mr. GIUDICE. That's right.

Mr. TAKANO. But the market alone doesn't seem to be able to move us in this sort of direction. It sometimes takes leadership——

Mr. GIUDICE. Absolutely.

Mr. TAKANO. —through government-funded efforts.

Mr. GIUDICE. Yes, that's completely appropriate. I—and you look at the profitability in the energy industry of equipment and services that are provided to this industry, versus the profitability in the Intel example or the pharmaceuticals example, and they're just—the private sector isn't making the kind of money in this industry to justify spending money on concepts that could, in fact, bear great benefit for society. And this is a very appropriate role for federal leadership to stand in and say, let's figure out what might make sense here, and then when it's ready, the federal government can step back and the private sector can take it forward for commercial deployment and bear full fruit.

Mr. TAKANO. I think about how geography and circumstances forced a nation like Japan to move in certain directions, and our relative geographic situation where we had abundant resources, we didn't have to think like they did, but—like they did, but I think about the way that they began to dominate the car market, the design of their cars and, you know, and the—they gained a competitive edge, and I'm worried about our Nation keeping a competitive edge in R&D and also in the ways we can bring this technology to market, or transfer that technology, transfer that knowledge.

My time is up, Mr. Chairman, and I will yield back.

Chairman WEBER. Gentleman yields back. Thank you.

I recognize the Chairman of the Full Committee, Chairman Smith.

Chairman SMITH. Thank you, Mr. Chairman. And, Dr. Whitacre, let me apologize for not hearing your testimony; I had to go give a quick speech, but I'm glad to be back. And I am also sorry I didn't get to hear all the questions that were posed by my colleagues, so I may be plowing some of the same ground.

But let me direct my first question to Dr. Gyuk, if I could, and it is this. First quick question is, you may have seen Tesla announce yesterday that they were announcing a new sort of home storage battery and a new industrial strength battery that presumably had better storage capability than others. I don't know how much information you might have read about Tesla's new batteries, but do you have any comment on them?

Dr. GYUK. My information is roughly the same information you have. I hear the public announcements. Tesla has a very fancy luxury car. They have talked about residential batteries, but they really do not have any major part of the market. And I wish them well. If they succeed then energy storage will profit from it as a whole.

Chairman SMITH. And I'm guessing it's incremental progress, not something that's explosive perhaps, or not something that's a major breakthrough, but they are on the forefront of car batteries in general, so that's why we tend to look to them maybe for some of the most—greatest advances in battery storage.

Dr. Virden, you mentioned in your testimony that I heard that there are number of gaps in our knowledge about developing the next generation battery, and looking for the next breakthrough. Given those gaps, do you want to give us any kind of a timeline, any kind of a prediction as to when we might make those kind of breakthroughs that will dramatically change the way we use alternative forms of energy?

Dr. VIRDEN. Yeah, thank you for the question. I think what you're going to see, from my perspective, is two phases. You have companies who have taken technologies that maybe have been developed over the last five or so years and they're going to try to move those to the market, and they're going to try to improve them.

Chairman SMITH. Um-hum.

Dr. VIRDEN. We, for example, on that vanadium redox flow battery, which was a well-understood battery, it's been around for years, through some fundamental scientific investigations in solubility, we are able to increase the capacity by 70 percent. Not incremental, but kind of revolutionary.

So you're going to see, I think, those continued advances in the pipeline. Maybe five or ten years out are all kinds of ideas of—you know, every battery has an anode and a cathode, just like your car battery, and an electrolyte in between. And you see all kinds of press releases about a new anode material that's five times better than anything out there——

Chairman SMITH. Um-hum.

Dr. VIRDEN. —and it probably is, but as Mr. Whitacre—Dr. Whitacre was saying, when you put that in with an electrolyte and a cathode, and put it together and then try to scale it, all kinds of things don't work. Materials start to fall apart, the chemistry isn't well known, there's side reaction, and usually what that leads to is loss of performance, loss of safety. And we as fundamental scientists don't understand those basic mechanisms.

Chairman SMITH. Okay.

Dr. VIRDEN. So in this ecosystem, you need that fundamental research that continues to move the state of knowledge along so companies can take that and utilize it, and the unique tools that DOE provides they can utilize.

Chairman SMITH. Right.

Dr. VIRDEN. Then you need companies to spin out and move it along. And we do really undervalue the challenge of scale-up. I think you're exactly right. In every materials process I see, in an experiment in a lab like this big, it works perfectly. Then when you want to make thousands of them——

Chairman SMITH. Yeah.

Dr. VIRDEN. —it doesn't. And so I think that is the challenge is filling that U.S. pipeline of fundamental science that can spin off, and people can keep moving things forward.

And with respect to that ecosystem and why it's so hard to move things out, there's 3,000 utilities——

Chairman SMITH. Right.

Dr. VIRDEN. —in this country, and they don't have R&D budgets, and they don't have venture capital budgets.

Chairman SMITH. Right, yeah.

Dr. VIRDEN. And they've got—we've got private, we've got public, we've got co-ops. The fragmented market makes it very difficult for the ultimate end-user to do the R&D.

Chairman SMITH. Thank you, Dr. Virden. You said five to ten years, so I gather that's what you're thinking.

Let me ask the other witnesses real quickly my last question. What's—sorry. And that is, and you're welcome to mention your own companies as well, in the case of our last two witnesses today, but what do you think is going to be the next great breakthrough? And, Dr. Whitacre, we'll go to you, and then Mr. Giudice and then Mr. Gyuk.

Dr. WHITACRE. Thank you very much, Mr. Chairman. The—there is a tremendous amount—there's a lot of leeway in that question, I will say. It's difficult for us to—for me to speculate on which vector the breakthrough should be in. There's energy density, there's power density, there's cost, there is lifetime, there is sustainability. These are all different, you know——

Chairman SMITH. Yeah.

Dr. WHITACRE. —axes of innovation. And my sense is which axes is more—most important I believe is cost and lifetime. And the things that are going to move the bar in that are going to be the broad scale and adoption of maybe not necessarily completely different kinds of technologies, but understanding how to leverage our existing base to get it to the right price for the right durability.

Chairman SMITH. Yeah.

Dr. WHITACRE. It's lifetime cost of electricity that matters. Electrons are dollars.

Chairman SMITH. Thank you. Mr. Giudice, my time is up, so if you'll give me a brief answer.

Mr. GIUDICE. Sure. It's going to be less than three years, and it's actually demonstrating the technologies that are now just getting to the market that are going to show the kinds of improvements that we need. And it is all about cost.

Chairman SMITH. And what's the quick technology you're talking about?

Mr. GIUDICE. Well, I'm excited about Ambri, I'm excited about Aquion. There's a few others out there.

Chairman SMITH. Okay, great. Dr. Gyuk?

Dr. GYUK. We have driven down the cost of vanadium systems to a considerable degree. We are now thinking of taking that experience and going into new directions, but with the same general approach. Zinc iodide is a possibility. Metalorganics and completely organic electrolytes.

Chairman SMITH. Okay. Thank you all.

Thank you, Mr. Chairman.

Mr. MASSIE. [Presiding] Thank you, Chairman Smith. And because this is such an interesting topic, and we have such great witnesses, we're going to do a second round of questions, at the risk of not catching our airplanes. And I appreciate your indulgence if you're available to stay for more questions.

Mr. TAKANO. Mr. Chairman, you could always give me a ride in your car.

Mr. MASSIE. Yeah. It will get you there very quickly.

And at this point I yield five minutes to Mr. Takano from California.

Mr. TAKANO. Yeah, do you have a battery as part of your free-standing house in——

Mr. MASSIE. Yes, I have a 45 kilowatt hour lead acid battery that's 12 years old, and I'm looking for a replacement, by the way, so I want to talk to you after the hearing.

Mr. TAKANO. And you're completely off the grid, is that right?

Mr. MASSIE. Yes, sir.

Mr. TAKANO. Literally.

Mr. MASSIE. Literally. In this—and because of that, I understand the importance of batteries. I have 13 kilowatts of solar on my roof, but it does me no good when the sun goes down if the batteries can't hold the electricity. And some days, because I'm off the grid, the power is literally just kind of spilling out. It goes nowhere and doesn't get saved.

Mr. TAKANO. I know our Chairman is an expert himself, so I thought I'd ask him a question too.

The question for all of you if you can answer it is, really where do you see the greatest potential for targeting future federal R&D funding to support emerging markets for grid-scale batteries, how we can scale, you know, do the grid-level—I mean just how best can we target our federal dollars? And if it were me, I would try to raise the R&D levels of spending, but what more—what's—what do we need to do next? What are the next things we could do, given if you believe that there's a role for the federal government in the basic research? Go ahead, take——

Dr. WHITACRE. Okay, I'll take a crack. I sort of talked a bit about this already. My focus would really be to—I propose, and others have mentioned as well, that there are tens of amazing bench—like bench-scale results already out there that could be breathtaking and super innovative, but getting them to the next level, getting into something that is repeatable, demonstrable, that is scalable, there's a tremendous amount of fundamental and basic science in that process. And I often think that there's a boundary drawn between basic science and applied science that is maybe technically a little false. Right? There's a tremendous amount of basic fundamental research in the process of making more than one tiny example of something, and why—how do we make that work. And energy technologies in general are about replicating and scaling, and and this is one of the disconnects. It's so easy to do one thing, comparatively speaking, than having lived this, I can make you—and I did indeed make a very nice, very individual thing years ago, and my life's work the past six years has been making it repeatable.

Mr. TAKANO. Wonderful. Mr. Giudice?

Mr. GIUDICE. Yes, from my perspective, I think from a federal leadership standpoint, I would really move towards the demonstration and pull through from the market standpoint than just on the basic science. And I appreciate the purview of this Committee is really more of the R&D side of it, but I really believe that there's an enormous amount of work to be done, as the largest energy consumer in the world, to start incorporating more of these different types of technologies in the mix of the energy choices that the federal government is making, and then working through all of the policies and issues around federal and state regulations to be able to fully value what the economics—the potential economic value of storage would be, and figure out ways to help make sure that gets as fully appreciated as possible as soon as we can.

Dr. VIRDEN. I'm going to use the all-of-the-above response on this one. And I truly believe you have to have the basic research to provide the long-term foundation. You're exactly right. There's some really cool technology ideas out there, but if you don't have the applied sciences, where most of the battery work starts to fall apart is when you take it out of the lab, put it in a real world battery system, and it's that applied science that starts to troubleshoot and figure out why they're not performing the way they should. The theoretical densities are always really high. When you make one, it drops way down. And then you can't get the full feedback until you do demonstrations. And if you don't have all those parts of the ecosystem, it's hard to innovate rapidly.

Dr. GYUK. Couldn't agree more. And that's what our program has tried to do; take the applied ideas, drive them through developing the devices, and then get them out in the field and see how well it performs in the field in the real-life situation. And we need to have that entire chain from support of basic scientific research, through the scaling into prototypes and beyond, and the applications for the first early adaptors and demonstrations out in the field.

Mr. TAKANO. And just real quickly, do any of you believe that this—getting to where we want to go can happen without federal leadership? I'll take that as a—no one believes that.

Okay, well, Mr. Chairman, I yield back.

Mr. MASSIE. Thank you. At this point I yield myself five minutes. I can't wait.

TAKANO. Take as long as you want.

Mr. MASSIE. And I've been given permission to take even more time.

But the first thing I want to ask you about, I listened to your list of materials, Dr. Whitacre, in your battery, and I heard, you know, saline or seawater—saltwater and some other things, cotton, some magnesium maybe in there. I was glad I didn't hear unobtainium, you know. This is a problem that we have when we try to scale things from the lab, you know, theoretical to mass production is sometimes you pick a material that's hard to obtain or hard to find at those scales. And I think one thing we need to be careful of, and I know you mentioned vanadium and iodide, which aren't unobtainium, those are familiar, is that we don't trade one set of moral encumbrances for another if we design materials into our batteries that aren't available domestically, and I'm okay with free trade, but are only available in politically unstable regions. And so could you talk to that issue? Mr. Giudice, you mentioned your battery technology, does it have any unobtainium in it or any special sauce that we can't get in this country?

Mr. GIUDICE. Yeah, so thank you for the question. The formation of the company was all about cost, and it was all about getting to the lowest possible cost for the delivered energy solution, because we know that that's going to make the most significant impact. So the chemistries that we utilized, we're not public about, there's been a lot of research published on our chemistries and other chemistries from the group Sadoway work on campus. We haven't disclosed as a company what ours is, but it all starts with crustal abundance and local supplies as being very, very important. And you're right, the initial work on campus was ultrapure materials, working inside glove boxes, and looking at could this sort of chemical matching work as a battery. And the answer was yes. As an industrial company now, we're doing things in open air, and we're doing things from industrial grade materials, and it's working very, very well. So I think it's an appropriate concern to have because it's all about delivering as low a cost, and getting as much of an impact as we possibly can. And we're quite comfortable that we're on track to do that.

Mr. MASSIE. Would anybody else like to comment on that? Dr. Gyuk?

Dr. GYUK. Yes. There are two charts that I keep in my mind when I think about new technologies. One is the chart of crustal abundances, which tells you how abundant the things are in general, and it also has a subsection on what materials are industrial materials. Vanadium is an industrial byproduct of the steel industry.

Mr. MASSIE. Um-hum.

Dr. GYUK. So that's okay. The other one is the chart of electro—electric potentials. You need materials that give you a large voltage window. Can't be too large if you're dealing with water, otherwise you're producing hydrogen and you may explode. But these two together define the limits of what we look into, and that's why we are interested in organics which are basically carbon with stuff added, okay. And once you have the way to make it down pat, it should be fairly easy to produce industrially in quantity.

Mr. MASSIE. Because we're using carbon and hydrogen and oxygen, right?

Dr. GYUK. Yeah.

Mr. MASSIE. Okay.

Dr. GYUK. And simple materials.

Mr. MASSIE. All right. Well, thank you very much.

Now, I know that the constraints on a car battery are different than the constraints on a stationary application where you just go for cost and cycle time, and you don't have to worry about weight, but what occurs to me is that—you were talking about those fancy cars they make, and I heard my car being called fancy, but it's an 85 kilowatt hour battery and we're fast approaching 100,000 of those vehicles in, you know, domestically. It's—that's like 8.5, if I've got my decimal place in the right spot, 8.5 gigawatt hours of capacity running around in this country pretty soon. Is there a potential for using that wisely, Dr. Virden?

Dr. VIRDEN. I think there is. There's, you know, practical issues like if you do plug your car into the garage, who has liability for the battery——

Mr. MASSIE. Um-hum.

Dr. VIRDEN. —if you're using it for, you know, stabilizing the grid. Interestingly, we did a study of all NERC/FERC sub-regions and looked and said how many of the cars could you put on—electric vehicles on the grid right now region-by-region, and the places where you could put a lot of cars on the grid, and the grid could deliver the electricity needed to charge and interact, was the Midwest primarily, and it was the places that had a lot of coal and natural gas intermediate capacity. And interestingly enough, in the west, Washington State, Oregon, California, where we're hydro-dominated, you could put the least amount of vehicles on the grid and charge them, because of our—having to back water up behind the dam at night, and we don't have a lot of intermittent capacity. So people are looking at the idea. It makes sense. We could handle some of the distribution challenges, but there's still a ways to go to be able to get that transactive signal that would allow the battery to play in that grid market.

Mr. MASSIE. If you'll indulge one more question.

Mr. GRAYSON. That's fine.

Mr. MASSIE. All right. Dr. Whitacre, I know your company is making a battery and it's selling it into applications that seem to involve different levels of scale. It's sort of the unique feature of your battery; you can scale it up and down. And this is really a question to all of you, but I'll start with Dr. Whitacre. To what degree are we going to be dealing with distributed storage, like at the home scale, versus centralized storage, and is there even a cost-effective place where it makes sense to do home storage? And I start with you, Dr. Whitacre.

Dr. WHITACRE. Thank you. For sure it makes sense in some locations right now. Hawaii comes to mind as an obvious location where the cost of electricity is already so high, and the penalties with selling back to the grid during peak solar production hours is great, that people would just rather buy the battery and do it. And this is a fully distributed customer size meter model. There are other places around the world where it's even worse. People are—and I should point out that our most intriguing early markets are not domestic. We are selling—we are exporting to a variety of places; the Philippines, Malaysia, you know, everywhere else, where there are—the dominant mode right now is distributed diesel generation, and they want to get rid of that, it's expensive and dirty. They would rather go to solar and batteries. They want the right batteries. And——

Mr. MASSIE. That's what I tell people that want to go off the grid, there's only one thing worse than the battery problem and that's the generator.

Dr. WHITACRE. The generator, right. And——

Mr. MASSIE. I'm on my first set of batteries, but on my fourth generator so——

Dr. WHITACRE. Yeah. Yeah, a couple of our installations, yeah, we have some in northern California right now, they've been going for almost a year now and we really watch how often the generator comes on. That's a big satisfaction piece for the customer; how often—and usually we're lucky, most of the time in our installations it's just the, you know, the weekly turn on to maintain integrity of the generator. That's what you want to see. That's a key—it's a key like win for us if we have that.

So—but there are other places, to be honest, in North America especially where electricity is very cheap, the grid is very reliable, and it's hard to imagine that those residences will be wanting to go distributed off-grid.It's—from a financial perspective, it's a tough sell. But in those same areas, you may have some local grid issues or renewable issues where a more centralized storage infrastructure makes sense. So again, it's very locationally dependent.

Mr. MASSIE. Mr. Giudice.

Mr. GIUDICE. Sorry. I agree, and the markets are developing, and we'll see how they continue to develop. As you think through the 3, 4, 5, six years out, I do think it's going to make better sense to keep it at the grid level for the most part, and be able to share amongst your neighbors both the storage and the distributed generation that might be on everybody's rooftop or on everybody's hilltop, but not have to duplicate the storage investment on a building-by-building basis. I think that there will be better economic value from a societal standpoint by doing that. It's a very natural role for the grid to be able to provide that at the distribution level, and then be able to offset a lot of the other investments that would otherwise have to be made by doing it that way. But it's going to take some time to work out those business models and really be able to put that in place.

Mr. MASSIE. All right, my time has very much expired, and so I will yield time generously to Mr. Grayson from Florida.

Mr. GRAYSON. Thank you.

The basic idea of a battery, the anode, the cathode, the electrolyte, that idea is roughly 200 years old, about as old as our country, and it is interesting when you consider all of the other technologies that have been developed in the meantime; the telephone, the computer, television and so on, that we're still basically using the same model that was used 200 years ago.

Is there any realistic prospect of moving beyond that model for energy storage? Dr. Whitacre.

Dr. WHITACRE. There are certain thermodynamic realties about storing electricity and materials, and those realities drive us to a sort of bipolar design where you have two separate material systems that retain different positive and negative charges when you apply a current to them. It's hard to imagine a different paradigm using the materials as we understand them today to allow this. It is sort of—the anode and cathode are a natural reflection of thermodynamics, is the way I would put that. So my answer is, if you're talking about electrochemical storage, I don't think so. This is the paradigm. The key is to enhance our understanding and to maximize performance, and explore new material systems and new electrode designs and so forth.

Mr. GRAYSON. Mr. Giudice?

Mr. GIUDICE. So obviously, I think a point was made earlier that, as the grid exists now, 97 percent of the storage that's done on the grid is pumped storage, mechanically, compressed air energy storage, two projects are going. So from an electricity storage standpoint, there's alternatives, but from an electrochemical battery standpoint, I don't think there are alternatives. And then the third form of storage, thermal storage, is obviously being utilized in lots of different applications as another interesting way to store energy, not so much electricity.

Mr. GRAYSON. Dr. Virden?

Dr. VIRDEN. I would agree with the previous witnesses' comments, if you're trying to store electrons directly, the battery storage is really the only way to go about it. And it has practical challenges with, over those 200 years, I don't think we've been faced—we've had to face the real issues of batteries, but with transmission distribution constraints, renewables, we're now having to face directly, you know, how do we store energy in a battery.

Mr. GRAYSON. Dr. Gyuk?

Dr. GYUK. Yeah, I cannot—I need to agree with what you have heard so far. If you're doing electrochemistry, you have certain limitations on the system. Nonetheless, there are directions one can go in. I do not necessarily believe that lithium ion is the end all and be all, even for cars. We have things to go beyond, but they will not necessarily be, you know, totally different.

Mr. GRAYSON. Following up on my colleague's question regarding distributed versus centralized storage, it seems to me that one of the key factors in that regard, whether you store electricity or energy centrally, or whether you store it household-by-household or business-by-business, is whether there are any significant economies with scale in the storage that would make up for the transmission losses that you would encounter when you distribute that energy from a centralized source. So please tell me, again, starting with Dr. Whitacre, whether you see any likely economies of scale in storage of energy that would offset the transmission losses.

Dr. WHITACRE. Absolutely. I think, depending on where it is, you again—I keep on going back to this, but location specificity matters depends on how good your transmission and how close you are to a centralized power source. By typically, I mean there's an argument for some degree of distribution to either eliminate the cost and the issues of either augmenting or establishing a more centralized traditional grid backbone system, or indeed, just by the straight efficiency losses associated with transmitting power. If you generate electricity on—in a location, you're best apt to store it near or at that location. This is happening in Germany right now. There's a self-consumption incentive wherein folks are actually driven to put batteries in their residence because they're generating electrons in their residence, and they—it's a more efficient system. So yes, there is.

Mr. GRAYSON. So just to be clear, do you see a future of big storage, big batteries, or a future of small storage, small batteries?

Dr. WHITACRE. You know, I see an intermediate situation. There's probably an intermediate thing where there are—there's certainly not a single battery in the center of the country, right, and there's certainly not a battery in each of our pockets. There are—there's an intermediate distribution of storage where there's an optimal distribution. Maybe it's at a neighborhood level or at a block level, or something—if we were to really reduce this down to that kind of question. There is some optimal economy of size and distribution. I'm not sure exactly what it is, but it's probably more than—it's probably outside the residence, but smaller than an entire city.

Mr. GRAYSON. Mr. Giudice?

Mr. GIUDICE. Yeah, so the market will tell us, and we'll see as it goes forward. I do think it's going to make sense, as I think where Dr. Whitacre was going, towards the distribution side of the business as the dominant place to have it make sense. And it's not so much economies of scale of delivering storage, but it's economies of the application. So on the neighborhood basis where clouds are coming by and we're all solar generating on our rooftops, those clouds are sporadically shutting off different rooftops as they cover up the sun. The storage at each house would have a much different effect than if it was storage across that whole small grid area. And I think that in terms of reliability and reducing costs, we're probably going to find optimal levels at those kinds of applications, rather than any central generating storage or storage for every single household.

Mr. GRAYSON. Dr. Virden?

Dr. VIRDEN. I think it's going to be distributed at the substation level. So for me that's, you know, several megawatts in a few megawatt hours. This is beyond frequency regulation where you have tens of megawatts. That's the higher value-added market right now. I see the home market behind the meter as longer term, except in a few places like California and Hawaii.

That Tesla announcement, by the way, you'll get a battery pack that's $3,000, you still have to buy the inverter, so it's $4,500, and that would give you about 7 kilowatt hours. That's not going to take you off-grid. Our estimates to go off-grid in a home, you're spending $15,000 to $20,000 or more, so it's still expensive. The community application, to me, makes the most sense because you spread the cost and get multiple benefits.

Mr. GRAYSON. Dr. Gyuk?

Dr. GYUK. Yeah, we consider distributed storage to be on the distribution side, which means substation and maybe slightly above or slightly below. Size from 500 kilowatt to about 10 megawatt. Those, I think, are the easiest applications. If we are going to go into residences, it's not so much residences as small businesses, campuses, business parks, and so on, there it makes sense to be behind the meter. Individual residences are probably a market considerably in the future.

Mr. GRAYSON. Thank you. I yield back.

Mr. MASSIE. And as we close, I'm going to yield one more minute to my friend from California——

Mr. TAKANO. Just——

Mr. MASSIE. —Mr. Takano.

Mr. TAKANO. Just one quick question. What about any kind of systems that might generate hydrogen or—and store hydrogen, you know, just through electrolysis? I don't know the science of it, but—and in combination with a fuel cell.

Dr. WHITACRE. I can quickly comment on that. While this is completely technically possible, and folks are still looking at doing it, one reality is the roundtrip energy efficiency of that kind of system is, at best, 60 percent maybe on the very best day. Most of the time it's 50 percent or less. And it's simply because the thermodynamics of converting water to hydrogen, and then converting it back to water and getting electrons, and storing electricity through that process, is inherently inefficient. And so this is difficult to compete with the 80 or 90 percent roundtrip efficiency we have in batteries. And that's a big, big deal when we talk about each electron is worth money.

Mr. TAKANO. Thank you very much.

Mr. MASSIE. Well, in closing, I want to say this has been a very enlightening hearing, thanks very much in part to the quality of the witnesses and the quality of the questions. And it confirms what I—my personal experience which is, batteries are not sexy, okay. You know, buckets of acid in your basement do not evoke envy from your neighbors, even though blue solar panels on your roof might. And—but the reality is this is what's holding our country back, this is what's holding renewable energy back. In fact, this is holding nuclear energy back, this is holding coal-fired energy back. I mean all these peak issues, they apply to any energy source that we have. And so I think even though it's not as sexy as some of the other topics, it is fundamentally very important to moving forward in our country is to have a better battery. The world needs a better battery. So I thank you for making that point, and informing us today on some of the issues. I will say that we very much value your testimony today.

And the members—the record will remain open for two weeks for additional comments and written questions from Members.

And this hearing is adjourned.

[Whereupon, at 12:25 p.m., the Subcommittee was adjourned.]

Appendix I

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. Imre Gyuk

QUESTIONS FROM CONGRESSMAN DAN LIPINKSI

Q1. The grid is in transition to greater renewable generation, greater decentralized or distributed generation and greater intelligent control of generation, delivery and use. Storage can play a role in all of these transitions.

Q1a. Do we have a strategy for the "use case" for storage?

A1a. Energy storage can play a key role in the future electric grid and has already been demonstrated to be cost effective in specific markets (frequency regulation ancillary service markets operated by regional transmission operators and independent system operators, such as PJM). However, the overall size (in gigawatts) of these markets is relatively small and further research and development is required to make storage cost-effective for other applications. The current strategy for enabling storage deployment for other use cases focuses on two aspects: enabling storage to capture value from multiple applications and lowering the overall cost of storage devices.

Q1b. Where, how and at what cost does it make sense to deploy storage?

A1b. A recent use-case analysis conducted by the Office of Electricity Delivery and Energy Reliability's Energy Storage Program has shown that higher priced storage systems can be revenue positive when optimally sized and located to take advantage of certain multiple value streams.[a] These optimization strategies assess the technical requirements of the battery in conjunction with time-dependent pricing signals from multiple services to develop an optimal dispatch strategy for the storage system that maximizes return to the utility and ratepayer.

Q1c. As the cost of storage comes down, which applications will become the most attractive?

A1c. Since these value propositions are regionally dependent, the Department of Energy (DOE) is supporting use-case analysis in selected regions to establish tools and strategies for optimization that can be expanded to other parts of the Nation at a later date. Further, DOE will work to implement a recommendation of the Administration's April 2015 Quadrennial Energy Review to conduct regional and state analyses of storage deployment

[a]http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23040.pdf

to produce a common framework for the evaluation of benefits of storage and grid flexibility, and a strategy for enabling grid flexibility and storage that can be understood and implemented by a wide range of stakeholders. As the cost of energy storage systems is further reduced, greater value can be derived from multi-use applications, and storage systems may become cost-effective for single applications such as renewables integration (particularly photovoltaics), balancing services, and transmission and distribution upgrade deferral.

Q2. Electric vehicles greatly reduce tailpipe emissions that cause poor urban air quality and contribute to climate change. I think many people realize the importance of researching battery technology for electric vehicles to improve range and charging time. Dr. Viden is working with Argonne, which is in my district, on improving vehicle energy storage. What I don't think many people realize is the importance of grid-scale energy storage for electric vehicles. Can you describe how the grid-scale energy storage enables confident deployment of electric transportation and optimal utilization of demand-side assets?

A2. Grid-scale energy storage enables confident deployment of electric transportation and optimal utilization of demand-side assets by providing a system-wide asset that increases the flexibility of the power system. Grid-scale energy storage allows better coordination of electricity production and use by serving as a buffer during times of high demand when there is not sufficient generation or by absorbing excess power during low load time periods. Currently, grid system managers have little control over the charging patterns for electric transportation. As transportation becomes increasingly electrified, this may cause undue stress from simultaneous charging. Grid-scale energy storage could relieve peak loads caused by this charging. Similarly grid-scale energy storage can be used by the power system to provide needed energy services to optimize deployment of other demand-side assets and reduce the need for individual energy storage units at load locations.

Q3. I think it is important to foster a culture of innovation and entrepreneurship in our country. The federal government has a critical role to play in getting technologies to market by helping start-ups bridge the valley of death. For example, Mr. Giudice's start-up company Ambri was funded in part by ARPA-E. Can you explain how DOE's efforts are helping bring technologies to market?

A3. Advanced Research Projects Agency-Energy's (ARPA-E) authorizing statute requires

ARPA-E to spend 5% of its annual appropriation on "technology transfer and outreach activities." (See 42 U.S.C. § 16538(n)(4)(B)). These activities are in furtherance of ARPA-E's statutory goal of accelerating transformational advances in energy technologies that result in new products and services. Due to the Agency's focus on the early stages of technology development and the limited duration of projects, ARPA-E expects each project team to establish a credible path to move technologies toward the market once the ARPA-E award is complete. ARPA-E refers to this as a "hand-off" for the next stage of the project. To facilitate these hand-offs, ARPA-E has a dedicated technology-to-market team that facilitates awardees building strategic relationships and developing critical business information for their projects. ARPA-E helps awardees develop a clear understanding of market needs to guide their projects' technical development. In addition, in accordance with ARPA-E's statutory requirement to identify "...mechanisms for commercial application of successful energy technology development projects, including through [the] establishment of partnerships between awardees and commercial entities...,"ARPA-E facilitates relationships with investors, government agencies, small and large companies, and other organizations that are necessary to move awardees to the next stage of their project development (See 42 U.S.C. § 16538(g)(2)(B)(vii)).[a] In addition, ARPA-E requires awardees to expend 5% of their award funding on technology-to-market efforts, which are reviewed by/coordinated with ARPA-E.

Q2. Pumped storage is a technology that seems to be more dependent on the permitting processes. So, in addition to improvements in the permitting process, do you see any role for the DOE in advancing pumped storage technology to enable it to become a more flexible, faster-response, storage asset?

A2. Pumped storage hydropower (PSH) currently represents the largest share of storage in the United States, with 42 pumped hydro storage plants totaling about 22 gigawatts of installed capacity, which is equivalent to about 2 percent of U.S. electricity generation capacity. There are currently an additional 37 gigawatts of projects that are in some stage

[a] More information about ARPA-E's Tech-To-Market activities is available on its website at: http://arpa-e.energy.gov/?q=arpa-e-site-page/tech-market-t2m.

of licensing at the Federal Energy Regulatory Commission.[a] Currently, about 97 percent of the Nation's energy storage capacity is derived from PSH technology.[b] The Office of Energy Efficiency and Renewable Energy's Water Power Program is actively engaged in the advancement of PSH through its investments in the development of modular pumped storage. In the Department's FY 2016 budget request, small-scale standardized modular PSH technology R&D aims to reduce powertrain costs and costs associated with civil works to support PSH deployment at a variety of scales, ranging from small distributed generation to utility-scale PSH. Specific R&D activities proposed for FY 2016 target: (1) scalable PSH facility designs using commercial off-the-shelf pumps, turbines, piping, tanks, and valves to achieve reductions in PSH deployment costs; and (2) hybrid PSH technology designs combining water storage with other forms of energy storage within energy and water delivery and collection systems.

[a] P. 3-10, Quadrennial Energy Review: Energy Transmission, Storage, and Distribution Infrastructure, April 2015, www.energy.gov/QER

[b] http://energy.gov/eere/water/downloads/2014-hydropower-market-report

Responses by Dr. Jud Virden

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

Hearing Questions for the Record
The Honorable Dan Lipinski

Innovations in Battery Storage for Renewable Energy

Wednesday, September 16, 2015

Questions for Dr. Virden

1. Electric vehicles greatly reduce tailpipe emissions that cause poor urban air quality and contribute to climate change. I think many people realize the importance of researching battery technology for electric vehicles to improve range and charging time. Dr. Viden is working with Argonne, which is in my district, on improving vehicle energy storage. What I don't think many people realize is the importance of grid-scale energy storage for electric vehicles. Can you describe how the grid-scale energy storage enables confident deployment of electric transportation and optimal utilization of demand-side assets?

Grid-scale energy storage can provide benefits for electric vehicle charging when installed on the premises (residential or commercial buildings). The benefits are attributable to deferred or avoided need for infrastructure upgrades of secondary transformer (usually a 50 kVA transformer pad-mounted or pole-mounted) and conductors from transformers to premises for the additional large load of EV charging. This benefit will improve the utilization of the grid-assets in the distribution system. A second benefit could be captured for regional and local grids that have a high penetration of solar PV capacity. Storage could be used to compensate for the sharp rise in net-load during dusk when the PV power output ramps down quickly and the load ramps up. In fact, the ramp-up of load is exacerbated with electric vehicle load when electric vehicles are plugged in the early evening. Grid-scale storage could mitigate the challenges associated with rapid increases in load and optimization with demand-side assets. The deployment of stationary energy storage may provide a higher value to the grid if it is deployed on the utility side of the meter (I.e. In the distribution system) not on the customer-side of the meter. Then the distribution system company could control it and may have more options to derive values from the storage device coordinated with the electric vehicle charging load and other demand-side assets.

Responses by Mr. Phil Giudice

AMBRI

Response to follow-up question for Committee on Science, Space and Technology
June 4, 2015

1) I think it is important to foster a culture of innovation and entrepreneurship in our country. The federal government has a critical role to play in getting technologies to market by helping start-ups bridge the valley of death. For example, Mr. Giudice's start-up company Ambri was funded in part by ARPA-E. Can you explain how DOE's efforts are helping bring technologies to Market?

A. DOE is an important resource in bringing new technologies to market on a number of fronts. For Ambri, DOE's ARPAe provided critical funding for research at MIT to advance the concept of liquid metal batteries to a point of demonstration necessary for Ambri to be formed and attract private capital. Ambri has now raised over $50 million from private capital sources and employs over 50 people as it advances toward delivering the commercial potential of our technology. Without DOE's ARPAe research funding the concept of liquid metal batteries would have never been advanced sufficiently to attract private capital.

ARPAe's hands-on involvement in the R&D that they support is critical to the success of emerging technologies. Primarily this assistance takes two forms. First, ARPAe program directors are constantly engaged in technical development, pushing teams to achieve milestones quickly. Increasing the speed of development through aggressive timelines and go-no-go milestones both accelerates innovation, decreasing the time required before commercialization of the technology, and imbues this aggressive goal-oriented culture in the technologists performing the work and bringing the technology to market. Second, ARPAe stresses the commercialization side of technology development, supporting only technologies that, with technical success, have the potential to make a large impact in the market. This manifests itself through a team of tech-to-market advisers that are deeply engaged with the technologists, helping them to think about what strategic markets should be pursued. This support is critical for early stage start-up teams that may be comprised exclusively of technologists. Combined, the involvement of program directors and tech-to-market advisers prepare early-stage, game-changing technologies to commercialize quickly with impact. To my knowledge, these features are unique to ARPAe among govemment funding organizations, and are key to its value as an organization.

Ambri is in discussion with other DOE capabilities to accelerate our progress including the national labs to provide third party testing, verification and market simulations as well as Office of Electricity and the Office of Energy Efficiency and Renewable Energy on potential demonstration projects.

Our country's energy future and our country's economic future are intimately and directly tied to creating and implementing our best energy technology solutions and DOE is a key agency to make this happen from supporting basic science research, development, demonstration, and commercialization including removing policy impediments and partnering with states on policy leadership.

Appendix II

Additional Material for the Record

PREPARED STATEMENT OF COMMITTEE RANKING MEMBER

EDDIE BERNICE JOHSNON

Thank you Mr. Chairman, and thank you to our witnesses for being here today.

Today we will hear about the Department of Energy's important role in advancing new large-scale energy storage technologies, which are critical to making our electric grid more efficient, reliable, and resilient, enabling a cleaner environment and lower costs for consumers.

The title of this hearing aside, improvements in energy storage are actually important for all forms of electricity generation, not just renewable energy production, as demand for electric power is often highly variable. Currently, high capacity power plants are required to meet expensive peaks in demand while operating below capacity for when demand is low. Grid-scale energy storage allows lower capacity plants to meet the same demand at a lower cost.

Dr. Gyuk, I am encouraged by DOE's work on large-scale energy storage solutions to date, and I frankly believe that given your track record and the size of this problem, your budget should be much, much higher than the $12 million that your entire program received last year.

It should be noted that another major contributor to early-stage research in this area is ARPA-E. This is yet one more reason that I was so dismayed that the majority proposed to cut this agency by 50 percent in their COMPETES bill just last week. I look forward to discussing the essential role that both ARPA-E and DOE's Office of Electricity play in accelerating the development and commercialization of these technologies here in the U.S.

As highlighted in the Department's first, widely praised Quadrennial Energy Review—which was released just last week—this area is vital to the future of America's energy infrastructure, and there is still much more work that needs to be done.

Thank you and with that I yield back the balance of my time

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