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# OPPORTUNITIES FOR THE EXPANDED DEPLOYMENT OF GRID-SCALE STORAGE IN THE UNITED STATES

## HEARING

BEFORE THE

## COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

ONE HUNDRED SIXTEENTH CONGRESS

FIRST SESSION

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# CONTENTS

## OPENING STATEMENTS


| | Page |
|---|---|
| Murkowski, Hon. Lisa, Chairman and a U.S. Senator from Alaska | 1 |
| Manchin III, Hon. Joe, Ranking Member and a U.S. Senator from West Virginia | 2 |


## WITNESSES


| | |
|---|---|
| Crabtree, Dr. George, Argonne National Laboratory and University of Illinois at Chicago, Director, Joint Center for Energy Storage Research | 5 |
| Davidson, F. Mitchell, Chief Executive Officer, U.S., Brookfield Renewable | 15 |
| Fowke, Ben, Chairman, President, and Chief Executive Officer, Xcel Energy Inc. | 59 |
| Kumaraswamy, Kiran, Vice President, Market Applications, Fluence | 81 |
| Ott, Andrew L., President and CEO, PJM Interconnection | 94 |


## ALPHABETICAL LISTING AND APPENDIX MATERIAL SUBMITTED


| | |
|---|---|
| American Council on Renewable Energy, et al.: | |
| Letter for the Record | 155 |
| Crabtree, Dr. George: | |
| Opening Statement | 5 |
| Written Testimony | 8 |
| Responses to Questions for the Record | 129 |
| Davidson, F. Mitchell: | |
| Opening Statement | 15 |
| Written Testimony | 17 |
| Responses to Questions for the Record | 143 |
| Fowke, Ben: | |
| Opening Statement | 59 |
| Written Testimony | 61 |
| Responses to Questions for the Record | 146 |
| Kumaraswamy, Kiran: | |
| Opening Statement | 81 |
| Written Testimony | 83 |
| Responses to Questions for the Record | 148 |
| Manchin III, Hon. Joe: | |
| Opening Statement | 2 |
| Murkowski, Hon. Lisa: | |
| Opening Statement | 1 |
| National Hydropower Association: | |
| Letter for the Record | 156 |
| Ott, Andrew L.: | |
| Opening Statement | 94 |
| Written Testimony | 96 |
| Responses to Questions for the Record | 151 |

# OPPORTUNITIES FOR THE EXPANDED DEPLOYMENT OF GRID-SCALE STORAGE IN THE UNITED STATES

**TUESDAY, JUNE 4, 2019**

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

The Committee met, pursuant to notice, at 10:16 a.m. in Room SD–366, Dirksen Senate Office Building, Hon. Lisa Murkowski, Chairman of the Committee, presiding.

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

The CHAIRMAN. Thank you for covering, Senator Manchin, I appreciate it.

I apologize to members of the Committee and to our honored guests. Thank you for being here this morning. I am going to apologize for my voice. I have kennel cough or something, I don't know. Awful.

[Laughter.]

We are here this morning to examine the expanded deployment of grid-scale energy storage. As with many of our hearings in this Congress, this is part of our Committee's ongoing efforts to address climate change by promoting the development of innovative and clean energy technologies.

Earlier in the year we held scene-setting hearings on opportunities for energy innovation and climate change in the electricity sector. We have discussed the prospects for advanced nuclear, renewables, energy efficiency, and carbon capture, utilization and sequestration, CCUS. We have just done some really supercool things in this Committee, just saying.

In those hearings, our witnesses emphasized that innovative technologies present a tremendous opportunity to reduce greenhouse gas emissions on a large scale, and that we can seize the opportunity by focusing on policies that will lower the cost and increase the deployment of these technologies.

So we are working hard in the Committee to do just that. We are taking this challenge seriously. We understand that if we are going to be serious about addressing climate change, we need to come together——

Senator MANCHIN. Hold on, here we go.

The CHAIRMAN. Thank you. This is teamwork, yes. Sorry, folks. There, look at how miraculous.

We are taking this challenge seriously. We understand if we are going to be serious about addressing climate change, we need to come together on practical and effective solutions that will reduce our greenhouse gas emissions. CCUS and nuclear energy will play a major role in these efforts and so will the topic of today's hearing, which is energy storage.

Put simply, energy storage is the process of capturing electricity from the grid and storing it for future on-demand use. This technology can take many forms, including pumped hydropower, grid-scale batteries, and flywheels.

Energy storage resources present a win-win opportunity to make the grid cleaner, more resilient, and more affordable. By storing power when it is cheapest and dispatching it during peak demand periods when power is most expensive, energy storage can significantly lower consumers' power bills. It can also help avoid or defer the need to build out additional electric generation, transmission, and distribution infrastructure.

Energy storage can play a key role in our nation's ongoing transition from large and predictable generation resources to a decentralized and more intermittent supply. Specifically, energy storage can pair with variable resources like wind and solar to make their output more consistent and avoid the wear and tear and uncertainty caused by irregular power flows.

We have certainly seen how this works back in my State of Alaska. Chugach Electric Association in Anchorage—they have deployed a flywheel and battery system to integrate fluctuating wind power and improve the energy stability. Kodiak also uses batteries and flywheels to help smooth out the wind energy there. We took Secretary Perry out last year. He was quite impressed by what he saw and how they had used the batteries to, again, smooth the whole system. Later this week, I am going to be going out to a fabulous little community of Cordova. They are going to have a ribbon-cutting there for a new energy storage system. They are going to pair a battery with hydropower to lower their energy costs in that little fishing village and reduce their reliance on diesel fuel. So as usual, Alaskans are innovating in some pretty exciting technologies.

Today we will examine the state of energy storage technologies, the regulatory and economic challenges of deploying more of these technologies, and how the Federal Government can partner with industry to get more of these technologies on the grid.

We have a great panel here with us this morning. Before I introduce them, I will turn to Senator Manchin for his opening statement.

Again, thank you, Senator Manchin and to my colleagues.

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

Senator MANCHIN. Chair Murkowski, thank you for holding a hearing today on grid-scale energy storage. I would like to welcome our witnesses and thank you all for joining us to talk about how

storage technologies can help us address some of our greatest challenges like climate change and energy cost.

But before we jump in, I would like to acknowledge one of our witnesses, Andy Ott. Andy has recently announced that he will be retiring at the end of the month after a successful 22—is that correct, Andy?—22-year tenure running the largest grid in North America, which is PJM. Andy, I want to thank you again for being here today, and thank you for your service all these years. We wish you nothing but the best in the future.

Grid-scale energy storage is a hot topic these days, and for good reason. Energy storage is needed to achieve the full potential of renewable energy. It is really a key enabling technology to a low carbon, modern grid that will help us achieve our carbon emissions reductions and address climate change.

Storage allows us to dispatch energy during times of peak demand, enhance the reliability of our grid, provide energy security and backup power for customers, and enable increased flexibility for helping to manage the continued growth of renewable generation on our system. Storage can also help defer distribution system upgrades and it can be installed quickly compared to traditional generation, bringing better value to customers while maintaining reliability.

Several members of this Committee have introduced bills to advance storage this Congress. The Administration proposed an increase in energy storage R&D and a new cross-cutting initiative to address the remaining barriers.

Furthermore, FERC has been working to make sure owners and operators of storage resources have fair and equal access to competitive wholesale energy markets. Meanwhile, system operators, utilities, and generators are working out the details in the energy markets.

With all this activity, I would say this hearing is going to be very timely.

I look forward to hearing from the panel about how to prioritize taxpayer dollars to create the most value for energy storage, both now and in the future.

I don't think anyone here will disagree that more work needs to be done to advance storage technology or bolster existing technologies like lithium-ion batteries, which is currently our best bet for chemical batteries.

In an editorial published on May 14th, Bill Gates stressed the importance of energy storage as one of the three key technology suites we should be pursuing in addition to advanced nuclear, carbon capture, and better transmission lines.

While battery technology has a long way to go, costs are coming down. In 2010 the cost of lithium-ion batteries was about $1,000 per kilowatt-hour. Now we are down to about $200 per kilowatt-hour which is great progress, but it is not enough.

There are problems with lithium-ion. I understand that we may not be able to get the cost down to much below $100 per kilowatt-hour. Also, we have only one active lithium operation in the U.S. and are otherwise dependent on foreign countries to supply this critical material, which is why I am the lead Democrat on Senator Murkowski's American Mineral Security Act, as well as the sponsor

of the Rare Earth Elements Advanced Coal Technology Act, which highlights the work that WVU and NETL are doing to extract these materials from coal by-products.

So while we discuss the advancement of storage technologies here today, I want to remind my colleagues of the importance of the supply chain of materials needed to actually manufacture energy storage resources.

Furthermore, energy storage won't be one-size-fits-all. We need several different types of storage technologies available to us so we can find the right tool for the job to store energy for later use.

I look forward to a robust discussion on what policies we need to get a suite of storage technologies ready to go and to the point of being cost-effective. We also need your help to see around the next corner to make sure we are preparing our energy grid to handle the energy demands of the future while also preparing our economy and our workforce to be competitive and robust in a global market.

I don't think anyone here will disagree that more work needs to be done to advance storage technology to bolster existing technologies like lithium-ion batteries. We have only one in the U.S.

I also briefly mentioned one type of storage that might not be as flashy and new as some of the other emerging technologies, but it is critical nonetheless. Pumped-storage hydropower represents 95 percent, and I repeat, 95 percent, of installed storage capacity in the U.S. today. It is renewable, zero carbon and tried and true.

I would like to see more pumped-storage deployment in states like West Virginia where we have the needed topography and water. I know that Brookfield already operates the Hawks Nest hydro facility in West Virginia and one of the largest pumped-storage hydro facilities in Massachusetts. I hope to hear about any pumped-storage development the panelists may have in the works and how we, in Congress, can help advance those efforts.

As I have said before, we need to be nurturing and advancing all technologies that can help us combat climate change.

I want to say one thing off script. The Chairman and I just came back from a trip to the Arctic, and we met with all the Arctic nations. What I took away from that trip was this: not one, including Russia, has used climate change as a political divider. They all know it is life or death up there for them to survive in that fragile ecosystem. It was unbelievable to walk away seeing everybody from the far right to the far left and anywhere in between trying to find an answer on how to subvert this, because it is real and it is damaging. It is going to affect all of our lives, and we have that responsibility. It was an unbelievable trip that was most educational and enlightening for me.

I look forward to working with my colleagues on the Energy Committee to explore how energy storage can be leveraged in conjunction with other grid assets to bring to bear the greatest benefits for the grid, its customers and its environments.

We have a lot to cover today, and I look forward to hearing from our panelists. I want to thank you, Madam Chairman, for this hearing.

The CHAIRMAN. Thank you, Senator.

You remind us all that we have a lot of good work to do in this Committee and I think that we are really helping to lead good, constructive discussions about what is out there, how we are working to make a difference when it comes to these technologies that will help deliver clean, efficient energy sources that reduce our emissions.

Let's begin with our distinguished panel this morning. Dr. George Crabtree is the Director of the Joint Center for Energy Storage Research (JCESR) at Argonne National Laboratory. We welcome you. Mr. Mitch Davidson is the CEO of Brookfield Renewable, welcome. Mr. Ben Fowke is the CEO of Xcel Energy. We have Mr. Kiran Kumaraswamy, who is the Vice President for Market Applications at Fluence, and Mr. Andrew Ott, who is the President and CEO of PJM Interconnection.

Dr. Crabtree, if you would like to begin. We would ask you to all try to keep your comments to about five minutes. Your full statements will be included as part of the record, then we will have an opportunity for questions.

Please proceed.

**STATEMENT OF DR. GEORGE CRABTREE, ARGONNE NATIONAL LABORATORY AND UNIVERSITY OF ILLINOIS AT CHICAGO, DIRECTOR, JOINT CENTER FOR ENERGY STORAGE RESEARCH**

Dr. CRABTREE. Thank you.

Chairman Murkowski, Ranking Member Manchin and distinguished members of the Committee, I'm honored to testify before you at this hearing.

This is a time of great transition in the electric grid. Efforts are underway to strengthen its resilience and reliability against extreme weather and against possible cyberattacks to decarbonize it and to incorporate renewable energy into it.

Ever since the grid was born in the 19th century, it has operated under a highly constraining principle and that is, we must generate electricity at the same rate that we use it. This requires minute-by-minute matching of generation to demand and this elaborate balancing act has serious downsides. One is that we must build the grid to meet the peak demand and the peak demand is about 40 percent higher than the average demand. That means that we're building 40 percent more infrastructure than we need. If energy storage were cheap enough, we could imagine a fully modern grid, running continuously at its most efficient level to meet the average demand. The modern grid would store excess generated electricity when demand is low and release it when demand is high.

With regard to expediting the grid transition, I would like to share a few fundamental messages with the Committee. First, energy storage plays many pivotal roles in all sectors of the grid, that includes electricity generation, transmission and distribution. There are probably more than 20 pivotal roles that must be addressed. Second, energy storage technology is advancing rapidly but we urgently need significant research advances to develop the storage technologies that will enable the full transition to a modern grid. Third, we are just now discovering through early stage de-

ployments the best practices for deploying energy storage in the highest impact and most cost-effective manner. We need to encourage many more early stage deployments to learn what works and what does not work. Lastly, storage plays a central role, not only in transforming the electric grid, but also in transforming other critical areas of the economy, that includes ground-based transportation through electric cars and trucks and aviation through air taxis, package delivery, and regional passenger flight. What's more, the military has all of the storage needs of the civilian economy as well as special storage needs for surveillance, weaponry and resilient worldwide bases that operate independently of the local grid for up to several months. Advances in storage for the grid will spill over to advance the frontiers of these other critical areas of the economy.

What unites all of these messages is the single key message, the urgent need to advance the state-of-the-art of battery R&D.

Congress and the Federal Government have taken the challenge seriously with the creation in 2012 of the Joint Center for Energy Storage Research, or JCESR for short. JCESR is led by Argonne National Laboratory. At its foundation, JCESR comprised 20 leading R&D institutions, including national labs, universities, and industry. These institutions have been working collaboratively to create the battery science and technology needed to support the emerging transformations of the electric grid, as well as ground transportation and flight.

JCESR has drawn its talent from across the United States, including MIT in the East, Lawrence Berkeley National Lab in the West, and everything in between. Such a collection of energy storage talent, it's a real dream team, cannot be found in any single institution.

As the saying goes, "The proof is in the pudding." In its first 5 years JCESR has many accomplishments to its credit and you can read what those are in my written testimony, but most important, JCESR promised to deliver two prototype batteries, one for the grid and one for transportation. In fact, JCESR actually delivered four prototypes, two for the grid and two for transportation. This effort led to important breakthroughs in advancing the state-of-the-art of four types of advanced batteries beyond the conventional lithium-ion.

Three numbers give you a quick sense of JCESR's impact: 450 scientific journal publications to date; 95 graduate student and post-doctoral alumni now working in academia, national labs and industry to advance U.S. battery research and development; and the formation of three startups. One of those startups, Form Energy, is pursuing commercialization of one of JCESR's prototypes—a water-based, air breathing sulfur battery.

In September 2018, the Department of Energy renewed JCESR for a second 5-year period. In the renewal, JCESR is shifting its focus from particular battery systems to transformational battery materials. We realized toward the end of our first term that even if all four of our prototypes went to commercialization, this would not come close to satisfying the urgent need for a diversity of new battery materials for a diversity of emerging applications.

In closing, I'd like to reiterate that energy storage will play a vital role in the transformation of the electric grid spanning generation, transmission, and distribution. We're still in the initial steps of that transformation, but we have not yet walked through the door. Achieving this transformation requires developing an energy storage ecosystem that spans research development and deployment.

Thank you.

[The prepared statement of Dr. Crabtree follows:]

Written Statement of

**George Crabtree**
**Argonne National Laboratory and University of Illinois at Chicago**
**Director, Joint Center for Energy Storage Research (JCESR)**

**Before the**
**Committee on Energy and Natural Resources**
**United States Senate**

**Hearing on:**
**Expanded Deployment of Grid-Scale Energy Storage**

**June 4, 2019**

Chairman Murkowski, Ranking Member Manchin, and distinguished members of the Committee, I am honored to testify before you at this hearing. This is a time of great transition in the electricity grid. Efforts are under way to strengthen its resilience and reliability against extreme weather events and possible cyber attacks, decarbonize it, and incorporate renewable energy into it as the cost of wind and solar electricity falls to compete with fossil fuels. In addition, rooftop solar panels require conversion from one-way to two-way electricity flow to allow local solar energy distribution on the grid. Moreover, as electric vehicles penetrate the marketplace more deeply, the grid will see great new opportunities for electricity supply and domestic job growth. Energy storage is critical to advancing all of these historic transitions.

Ever since the grid was born in the 19$^{th}$ century, it has operated under a constraining principle – we must generate electricity at the same rate that we use it, requiring minute-by-minute matching of generation to demand. This elaborate balancing act has serious downsides. One is that we must build the grid to meet the peak demand, about 40% greater than the average demand. This means we are building 40% more infrastructure than we need, and often operating the grid at peak demand with the least expensive, outmoded means of energy generation because this equipment runs only a few hours a week, and there is no economic justification to upgrade or replace it. If storage were cheap enough, we can imagine a fully modern energy generation system running continuously at its most efficient level to meet the average demand, storing excess generated electricity when demand is low, and releasing it when demand is high. Energy storage enables replacing the present just-in-time-delivery grid with an inventory-based grid that dramatically lowers capital and operating costs while raising resilience, reliability, and flexibility.

I would like to share a few fundamental messages with the Committee:

- Energy storage plays many pivotal but distinct roles in all sectors of the grid – electricity generation, transmission, and distribution.

- Although energy storage technology is advancing rapidly, we urgently need significant basic and applied research advances to innovate and develop the storage technologies that will enable the full transition to a modern electricity grid.
- We are just now discovering, through early stage deployments, the best practices for deploying storage in the highest impact and most cost-effective manner. We need to encourage many more early stage deployments to learn what works and what does not work, and to set a deliberate strategic path for the full deployment of energy storage on the grid.
- Storage plays a central role not only in transforming the electricity grid, but also in transforming other critical areas of the economy, including ground-based transportation through electric cars and trucks, and aviation through air taxis, package delivery, and hybrid-electric regional passenger flight. The military has all of the storage needs of the civilian economy, as well as special storage needs for surveillance, weaponry and the resilience for its foreign and domestic bases to operate independently of the local grid for up to several months. Advances in storage for the grid will spill over to advance the frontiers of these other critical areas of the economy.

Let me briefly elaborate on those points, as well as my organization's contributions to advancing the state-of-the-art of energy storage.

*Diverse Roles for Storage in the Electricity Grid*

Electricity storage plays a pivotal role in the generation sector of the grid. It reduces or eliminates generation peaks and valleys, and allows generation to run steadily at its most efficient level. Storage is critical to integrating variable wind and solar electricity in the grid, smoothing variations on time scales of seconds to minutes, and time-shifting excess afternoon solar-generated electricity by several hours to meet evening peak demand. In the transmission sector, batteries at both ends of a transmission line allow the line to operate continuously at its highest efficiency, deferring or avoiding the high cost of new or upgraded transmission lines. In the distribution sector, storage is needed for managing the two-way flow of electricity from rooftop solar panels back to substations for distribution to other users, for managing demand and reducing demand charges, and for providing resilience, reliability, flexibility, and high-quality digital power. These "non-wires" solutions to grid challenges are becoming more common as we deploy more storage to the electricity grid.

For these reasons, there appears to be wide, bipartisan and bicameral support for the deployment of grid-scale energy storage. In particular, the Better Energy Storage Technology (BEST) Act would authorize $300 million over five years to reduce the cost of promising grid-scale energy storage systems. This bill would further promote research and development efforts that hold the potential of considerably improving the efficiency of the nation's electrical grid.

*Significant Storage Advances Needed*

Achieving the vision of a reliable, resilient and flexible grid taking full advantage of renewable electricity requires significant advances in energy storage. First, storage must become much

less expensive. Although the cost of storage has fallen faster than the cost of solar panels, it must fall significantly further. The present cost of lithium-ion battery packs, about $200/kWh, must fall by a factor of two or more to make storage economically appealing across all its uses in the grid. In addition, we must be able to purpose-design batteries for a diversity of applications in the grid spanning generation, transmission, and distribution. An example is long-duration storage, needed to fill in for renewable generation when the wind does not blow or the sun is blocked by clouds for as many as seven days in a row. These long, cloudy, or calm periods are common in weather patterns in the Northeast and Midwest. The present generation of lithium-ion batteries can optimally discharge for about four hours, much too short to span many weather-related generation gaps. New battery materials, concepts, and technology are needed to meet the challenges of long-duration-discharge energy storage.

*Early-Stage Storage Deployment*

Recently, two major storage deployments have demonstrated the value of large-scale energy storage on the grid. A massive natural gas leak in the Aliso Canyon reservoir discovered in 2015 prompted the utility to solicit 70 MW of storage to replace gas peaker plants needed to maintain reliability during summer peak demand. The storage went on-line in January 2017 and has operated as expected for over two years, demonstrating the value of energy storage at scale for grid resilience and reliability. In December 2017, a second larger storage system, 100 MW, was deployed in South Australia to stabilize that grid, with equally satisfactory results. A third even larger storage system, 300 MW, has been approved for deployment at Moss Landing, California.

These early stage deployments of storage at scale demonstrate that large-scale batteries can solve grid challenges without incurring unexpected downsides. Despite their success, they represent only a small fraction of the many critical needs for energy storage related to the generation, transmission, and distribution sectors of the grid. Many more early stage deployments are needed to learn what works and what does not, so that we may set in place robust policy and regulatory structures to manage the complete transition of the entire grid to a fully modern state.

*The Wide Reach of Electricity Storage*

Storage plays a central role not only in transforming the electricity grid, but also other important areas of the economy. Electric vehicles are a step in the emerging transformation of transportation from exclusive reliance on personal car ownership to alternative modes of transportation, such as shared rides and mobility as a service. Batteries for electric vehicles share many challenges with batteries for the grid: higher capacity, faster charging, lower cost, greater safety, and longer life. While the external form of an electric vehicle battery and a grid battery may be different, the advances needed in the underlying materials and atomic-level electrochemical phenomena that power the two kinds of batteries are remarkably similar.

Electric vehicles unite, for the first time, the electricity grid and transportation, the two largest energy users in the economy. Powering vehicles with electricity dramatically expands their flexibility, allowing them to run not only on gasoline but also on wind, sunlight, hydropower,

nuclear power, or natural gas. All these domestic electricity sources decrease our dependence on imported oil. Moreover, electric vehicles are fast becoming a major new market for electricity, and may require up to 30% more electricity generation to satisfy the driving demands of the country. This significant growth in electricity demand will drive building considerable new domestic infrastructure spanning the generation, transmission and distribution sectors of the grid, as well as rolling out a national network of charging stations for electric vehicles. This extensive infrastructure expansion will create numerous domestic jobs and introduce a new horizon of opportunity for the electricity grid.

Beyond propulsion power sources for cars, buses, and trucks, batteries are beginning to penetrate flight. We already have drones capable of remotely inspecting the moisture levels of farmers' fields, surveying the condition of roads and bridges, and delivering mail-order packages. Boeing and Airbus are working on vertical-takeoff air taxis to take commuters to work and hybrid electric aircraft for regional passenger service, both set to debut by 2025. Batteries needed for electric flight must perform a step above those needed for the grid or ground transportation, but they are built on the foundational knowledge of materials and electrochemistry created in developing grid and transportation batteries.

*The Urgency of Battery Research and Development*

These examples illustrate the urgent need to advance the state-of-the-art of battery research and development. Batteries and energy storage are central to the emerging transformations of the electricity grid, of ground-based electric transportation, and of electric flight. Congress and the federal government have taken this challenge seriously, with the creation in 2012 of the Joint Center for Energy Storage Research (JCESR), an entirely new kind of Energy Innovation Hub designed to meet the battery needs of the future.

JCESR is led by Argonne National Laboratory, whose mission is to accelerate science and technology that drive U.S. prosperity and security. At its foundation, JCESR comprised 20 leading battery research and development institutions, including national labs, universities, and industry. These institutions have been working collaboratively to create the battery science and technology needed to support the emerging transformations of the electricity grid, ground transportation, and flight. JCESR's talent is drawn from across the United States, including MIT in the East, Lawrence Berkeley National Laboratory in the West, and everything in between. Such a collection of talent – a real dream team – cannot be found in any single institution. The battery challenge requires a major effort, combining the frontiers of electrochemistry, high-performance computing, atomic-level materials characterization, and advanced synthesis and discovery of new materials. Each of these frontiers has its own group of special techniques and leading researchers. Bringing them all together in a single collaborative unit is the only way to make the needed progress in battery technology.

In its first five years, JCESR introduced new tools for simulating and characterizing battery materials at atomic and molecular levels and for techno-economic modeling of new battery systems. Techno-economic modeling is central to JCESR's strategy, guiding its choice of particular battery systems to pursue based on their expected performance, cost, and materials

challenges. JCESR took to a new level computer simulation of battery materials before making them in the laboratory. Its computer simulations have permitted comprehensive atomic- and molecular-level prediction of capacity, voltage, and mobility of ions in solid electrodes and liquid organic electrolytes. For example, JCESR simulated 1800 combinations of working ions and cathodes in the search for a cathode for a magnesium battery, finding five that looked promising. We then synthesized two of the five and discovered that they worked. Exploring this many combinations of materials could never have been done in the laboratory, even with an army of graduate students devoting their full attention to the task. JCESR's high-throughput computer simulation dramatically accelerates the pace of materials discovery.

JCESR's many other significant advances include

- invention of inexpensive nanoscale polymer membranes that selectively transmit or block organic molecules on the basis of size,
- introduction of the Electrolyte Genome, a comprehensive database of predicted properties of liquid organic molecules for next-generation batteries,
- development of the concept of redox active polymers or "redoxmers" for a new kind of high-performance, low-cost flow battery,
- discovery of high mobility pathways for doubly charged ions, such as magnesium in crystalline electrodes and electrolytes, and
- pursuit of a promising new direction for lithium-air batteries with high energy density and low cost.

Most important, JCESR promised to deliver two prototype battery systems, one for the grid and one for transportation. At the end of five years, JCESR delivered four prototypes, two for the grid and two for transportation. Our prototype development effort led to several important breakthroughs. For portable applications such as vehicles, we demonstrated innovative batteries based on magnesium, zinc, and calcium, each of which carries two charges instead of the single charge on lithium, doubling the energy stored or released by these ions on each charge or discharge cycle. We developed the concept of sparingly solvating lithium-sulfur batteries to raise their energy density while prolonging their cycle life. For stationary applications such as the grid, JCESR's new concept of redox-active polymers or "redoxmers" promises flow batteries with low cost, high capacity, and self-healing properties to extend their life. Finally, JCESR's invention of inexpensive aqueous air-breathing sulfur batteries for long duration storage fills a long-standing and challenging gap in grid storage technologies.

JCESR spun out three startups in its first five years. Blue Current is pursuing solid state electrolytes. Sepion is commercializing inexpensive size-selective polymer membranes. Form Energy is commercializing JCESR's long-duration inexpensive flow battery based on sulfur, water, and oxygen. With Form Energy, JCESR took the new idea of this aqueous, air-breathing sulfur battery for long duration storage from initial concept to commercialization in less than five years.

At the end of its first five years, JCESR won the Secretary of Energy Achievement Award for its development of new strategic and operational concepts for large collaborative projects, such as

Energy Innovation Hubs. This confirmation of our success allows us to push our research boundaries even more aggressively going forward.

In September 2018, the Department of Energy (DOE) renewed JCESR for a second five-year period. In the renewal, JCESR shifted its focus from particular battery systems to transformational battery materials. We realized toward the end of our first term that even if all four of our prototypes were commercialized, this would not come close to satisfying the urgent need for a diversity of new batteries for a diversity of emerging applications in the electricity grid, ground-based transportation, and electric flight. Moreover, the roadblock in creating new battery technologies is typically lack of high performance materials. To address these challenges, JCESR shifted its focus in its renewal to transformational battery materials including anodes, cathodes, electrolytes, and interfaces that will enable a diversity of purpose-designed batteries for a diversity of uses. JCESR will work with end users, such as its start-up Form Energy, to create specific batteries needed for specific purposes.

JCESR's renewal introduces a new approach to transformational battery materials: building them "from the bottom up," atom by atom and molecule by molecule, where each atom or molecule plays a prescribed role in achieving targeted overall materials behavior. This kind of atomic- and molecular-level materials design would not have been possible ten years ago because our knowledge of the atomic and molecular origins of electrochemical behavior was incomplete. The advanced atomic-level computer simulation and experimental characterization of battery materials in JCESR's first five years are part of the foundation for our new bottom-up materials design approach. Introducing such innovative approaches helps to secure America's energy future and deliver economic—and scientific—competitiveness and growth.

JCESR's renewal provides a natural platform for strengthening broader research alignment among its partner institutions. JCESR's partners are working to ensure that their broader lab strategies and capabilities beyond the JCESR program are complementary and closely aligned with long-term DOE goals, such as research challenges for future U.S. battery manufacturing needs. This fostering of research alignment raises the effectiveness of the labs as a whole, collectively champions engagement with U.S. industry, and serves as a role model for cooperation across the national lab and university systems.

JCESR is sponsored by the DOE Office of Basic Energy Science in the Office of Science to pursue fundamental research on the materials and phenomena of next-generation batteries. In this role, JCESR frequently interacts with the applied energy offices of the DOE, including the Office of Energy Efficiency and Renewable Energy and the Office of Electricity. On its renewal, JCESR added a new position, liaison with the Office of Electricity, to better understand its materials and performance needs and promote sharing of strategy, information, and results. In addition, JCESR interacts strongly with other DOE programs, including Vehicle Technologies and Advanced Manufacturing in Energy Efficiency and Renewable Energy.

*Conclusion*

Energy storage will play a vital role in the transformation of the electricity grid spanning

generation, transmission, and distribution. We are taking the initial steps of this transformation, but we have not yet walked through the door. Achieving this transformation requires enduring support of basic and applied research for energy storage. Disruptive fundamental research is essential to produce the transformative materials that will enable next-generation purpose-designed batteries for the diversity of storage needs on the grid. Equally important is the applied research needed to realize these batteries, and the innovative policy, regulatory, and business plans required to successfully deploy the batteries on the grid.

The societal pay-offs of next-generation energy storage for the grid will be enormous. Yet, the ultimate path to its development is uncertain, and the risk of failure is significant. This task is best assumed by research organizations that can tolerate that risk, such as universities, national laboratories, and multi-organizational Energy Innovation Hubs like JCESR. As the winning technologies become evident, the private sector will adopt and deliver them to the public. This combination of high-risk, high-reward public sector research enabling innovative private sector development and deployment is essential to the transformation of the electricity grid to its fully modern form.

The CHAIRMAN. Thank you, Dr. Crabtree.
Mr. Davidson, welcome.

**STATEMENT OF F. MITCHELL DAVIDSON, CHIEF EXECUTIVE OFFICER, U.S., BROOKFIELD RENEWABLE**

Mr. DAVIDSON. Chairman Murkowski, Ranking Member Manchin and members of the Committee, my name is Mitch Davidson. I am the CEO of Brookfield Renewable's U.S. business, and I appreciate the opportunity to be here today.

Brookfield Renewable owns and operates one of the world's largest renewable energy portfolios which includes 900 renewable power facilities with a total install capacity of 17,500 megawatts. Included in our U.S. portfolio are 137 hydro facilities—many of which are frequently the largest taxpayers in the rural communities in which they reside, 26 wind farms, and 490 solar installations, totaling 6,500 megawatts of capacity. We operate these resources within a binding global commitment to safety, environmental responsibility and community engagement.

Hydropower is a proven long-life resource providing critical, baseload and peaking power and delivering a variety of important reliability benefits, all with zero emissions. Hydropower is a most efficient technology for storing energy and is capable of providing a firm capacity with the ability to follow dispatch orders without the loss of its renewable resource.

These assets also provide valuable ancillary services such as operating reserves, frequency regulation, power support and black start capabilities.

Reservoir hydroelectric resources store water during the spring snow melt or rainy season. We think of this as stored fuel and turn that stored fuel into energy during the peak periods of summer and winter months. For example, on a single river in Maine, we control three large reservoirs and seven generation stations which provide the fuel security equivalent of 30 days of stored energy.

Pumped hydro has the ability to become a significant load during periods of low demand. This excess load can minimize production changes for large baseload units, thereby enhancing their efficiencies and minimizing the risk associated with operational changes or capture energy from intermittent resources which on many occasions would have otherwise been curtailed during those periods.

The 600-megawatt Bear Swamp pump hydro facility, which is jointly owned by ourselves and Emera Energy, began generating electricity in 1974. During the charging cycle the facility pumps approximately 4,600-acre feet of water uphill into a reservoir. The facility can reach maximum output from a standstill in three minutes and is capable of taking 600 megawatts of excess generation off the grid to generating 600 megawatts for the grid in under 30 minutes. This 12,000-megawatt swing with the ability to maintain output for up to six hours are reasons why the ISO New England operation staff believe the facility is critical to the reliability of the electric system.

Bear Swamp is currently undergoing an upgrade and a relicensing. Once completed, it will be capable of producing 660 megawatts at six percent greater efficiency with a reduced time of

pumping to full capacity by an entire hour. Following these upgrades, Bear Swamp will have essentially two new generation units thereby prolonging the useful life of the asset up to 50 years.

Hydropower is the largest generator of renewable energy in the country providing grid resiliency, fuel security and ability to balance valuable resources. These assets should be considered energy infrastructure, critical energy infrastructure. Hydropower has consistently delivered these attributes during severe weather conditions, weather conditions which have posed challenges for many other generation resources. For example, during the Northeast severe cold weather event that occurred December 2017 through January 2018, our hydroelectric generation resources continued to operate at their planned levels of production with many of our assets operating at levels of 50 percent above expectations.

Hydropower facilities are capital intensive assets. Unfortunately, many renewable portfolio standards favor new renewable generation to existing hydro, putting hydro assets which have superior dispatch capabilities at an economic disadvantage. As policymakers consider ways to further reduce emissions, it is critical that existing hydropower be treated on par with other renewable resources.

In closing, I would like to reiterate that hydropower is a critical component of this country's energy infrastructure and a resilient electric grid. With the right regulatory policies and economic signals, hydropower will continue to enable the large-scale development of valuable renewable energy resources.

I appreciate your time, and I look forward to your questions.

[The prepared statement of Mr. Davidson follows:]

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**Testimony of F. Mitchell Davidson**
**Chief Executive Officer, U.S.**
**Brookfield Renewable**

Hearing of the U.S. Senate Energy and Natural Resources Committee
June 4, 2019
*Topic: Energy Storage*

**Introduction**

Chairman Murkowski, Ranking Member Manchin, and members of the Committee – thank you for inviting me to testify on pumped hydro and the other energy storage attributes of hydropower. My name is Mitch Davidson. I am the U.S. CEO for Brookfield Renewable.

Brookfield Renewable Partners L.P. ("Brookfield Renewable") owns and operates one of the world's largest renewable power portfolios, containing 900 renewable power facilities in North America, South America, Europe, India and China with a combined installed capacity of 17,500 megawatts. We operate these resources with an abiding global commitment to safety, environmental responsibility and community engagement.

Our U.S. portfolio includes 137 hydro facilities[1], 26 wind farms, 490 solar installations, a thermal facility, and a battery project, all totaling 6,500 megawatts of installed capacity. This portfolio includes the 600 megawatt pumped hydro facility called Bear Swamp, located in the Commonwealth of Massachusetts.

[1] The hydro facilities are 51 run of river, 85 reservoir hydro, and 1 pumped hydro facility.

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**Role of Hydropower**

Hydropower facilities provide carbon-free power, local tax revenues, recreational opportunities[2], and both direct and indirect jobs. Brookfield Renewable's hydroelectric projects are often located in less developed rural areas and frequently represent the largest taxpayer in their local communities, providing critical funds for local schools, fire departments and other public services.

Hydropower is the original renewable energy resource. It is a proven, long-life and reliable energy resource, providing critical, clean, baseload and peaking power and delivering a variety of important reliability benefits to the electricity grid, all with zero emissions. Reservoir and pumped hydro are the only renewable energy resources capable of delivering dispatchable, firm energy across peaking periods.

I believe we can all agree that the key benefit offered by energy storage is the ability to save energy during periods of low demand and then deliver that same energy back to the grid during periods of peak demand. Pumped hydropower can shift energy supply across hours, temporarily storing energy from the grid when there is an abundance of supply and injecting it back into the grid later when it is needed. Reservoir hydropower has a similar ability to shift energy production by days, weeks, months and even seasons, storing large quantities of clean renewable energy for electric production during peak demand periods. Both act as important energy storage management tools for the grid, which enhances grid reliability and greatly improves grid resiliency.

**Reservoir Hydro**

Hydroelectric generation resources associated with reservoirs can store the water collected (you should think of this as fuel) during the spring snow melt or rainy seasons and turn that fuel into energy during the summer and winter months when it is needed the most. For instance, on a single river in Maine, we control 3 large reservoirs and 7 generation stations which provide the fuel security equivalent of 30 days of stored energy. Unlike most renewable generating facilities,

[2] Hydropower facilities with and without reservoirs often provide recreation areas for swimming, fishing, bird watching and boating.

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these units provide the flexibility to follow dispatch orders by increasing or decreasing their output in a manner necessary to best serve the fluctuations of electricity demand and they do so without the loss of renewable resources. This ramping capability also allows these hydroelectric resources to provide valuable ancillary services such as operating reserves, frequency regulation, VAR support, black start capability, and fast ramping.

**Pumped Hydro**

Many pumped hydro facilities in the U.S. were originally developed near large coal and nuclear plants. This occurred for three reasons: 1) to allow these large coal and nuclear units to achieve efficiencies by maintaining higher production levels during off-peak periods; 2) to store excess production from these facilities during off-peak periods for redelivery during peak periods of demand; and 3) to mitigate against the loss of these plants that are typically the largest contingency on the grid. Similarly, today, pumped hydro facilities are performing the same function, except instead of just helping to maintain large baseload generation units at efficient production levels during off-peak hours, pumped hydro is also capturing power deliveries from intermittent resources during periods of excess supply that would normally be curtailed during those hours and redistributing that energy to peak periods.

As has been raised before this Committee in the past, pumped hydro is one of the most efficient ways to store energy. With the right market signals, pumped hydro facilities can be designed to provide hours of firm, dispatchable energy across peaking periods. In addition to the long duration of storage, pumped hydro can also provide the other valuable ancillary services that I mentioned earlier.[3]

Pumped hydro facilities are massive infrastructure projects that require significant capital investments, add jobs in the rural areas where they are located, and when maintained properly, can last over 100 years. The generating and pumping machinery is designed and built to perform efficiently for 30-50 years and when that machinery is replaced or upgraded, that system will perform as if it were a new asset for decades longer.

[3] Operating reserves, frequency regulation, VAR support, black start capability, and fast ramping.

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**Bear Swamp**

The Bear Swamp facility began generating electricity 45 years ago in 1974. It is a 600 MW pumped hydro generating facility in western Massachusetts, jointly owned by Brookfield Renewable and Emera Energy. This facility uses energy from the grid during off-peak periods to pump approximately 4,600 acre feet of water uphill into its reservoir, and then uses that stored water during peak periods to generate energy and capacity during peak electric demand. The facility can reach maximum output from a standstill in 3 minutes and is capable of taking 600 MW of excess generation off the grid to generating 600 MW's for the grid in 30 minutes. That 1,200 MW swing as well as the ability to maintain its 600 MW rate of generation continuously for up to 6 hours are the reasons why the ISO-NE operations staff and CEO believes this facility is critical to the management of the electric system.

Bear Swamp is currently undergoing an upgrade and a relicensing. Following the upgrade, it will be capable of producing 660 MW at 6% greater efficiency by 2021 and will be able to reduce the time it takes to pump to full capacity by an entire hour, a significant improvement. Following the completion of the upgrades, Bear Swamp will have essentially two new generation units, thereby prolonging the useful life of the station by over 50 years.

**Pumped Hydro and (not versus) Battery Storage**

Most people today associate the term "energy storage" with batteries. I do not consider reservoir or pumped storage and battery storage to be an either/or choice. Each provide different but significant benefits. Battery storage can respond within a fraction of a second to system demands and is also able to provide some frequency regulation and voltage support. Also, the cost of battery storage has been declining rapidly which is a very positive trend as we look to integrate more storage into the electric system.

However, battery storage is not the tool for every job and there are important roles on the grid for reservoir and pumped hydro. We should be mindful of the role that hydropower will play in meeting the demands of the grid of the future. Some of our generation facilities have been relicensed multiple times, are over 100 years old and continue to generate efficient, safe and reliable energy. There is every reason to expect these assets to continue to provide those benefits well into the future.

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**Resiliency**

Grid resiliency – all the rage in energy discussions of the last few years - does not just mean coal and nuclear. It also means hydropower with its capability to provide baseload generation, to balance intermittent solar and wind generation, to offer fuel security and long-term energy storage, and to enhance grid reliability through its fast ramping and black start capabilities.

Hydropower should be considered critical energy infrastructure. As a generation technology, it is not only the largest generator of renewable energy in the country[4], but as nature's battery it provides resiliency, fuel security, and the crucial ability to balance the increasing penetration of variable renewables.

Hydropower delivers these attributes even during severe weather conditions that can pose a challenge for many generation resources. For example, during the severe cold weather that occurred from December 2017 to January 2018, our hydroelectric generation resources in New England continued to generate at their planned output and some resources operated at levels of 10-50% above their typical hourly output.

**FERC Licensing**

A FERC license on a hydro facility, issued under the Federal Power Act, can last between 30 and 50 years. This licensing process can easily exceed 5 years, and occasionally takes as long as 8-10 years to complete. The process requires a comprehensive review of all affected resources and includes input from FERC, multiple other federal and state agencies, and other stakeholders, which may include nearby residents, recreational and environmental interests, Native American tribes and other members of the local community. This effort and the resulting conditions, environmental mitigation and capital improvement requirements imposed through the new licenses routinely costs many millions of dollars and often results in operational limits which sacrifice the benefits afforded by these facilities. We are very familiar with the process as our company is the largest private holder of FERC hydro licenses in the country.

[4] EIA data; Energy Information Administration, FAQ "What is U.S. electricity generation by energy source?", March 2019, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

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**Energy Policy and Existing Resources**

While hydro power facilities may appear to operate nearly self-sufficiently, they are a capital-intensive resource, requiring significant periodic reinvestment to ensure reliable, efficient and safe operation. Unfortunately, many state renewable portfolio standards favor new renewable generation capacity to the disadvantage of existing renewable generation, putting existing hydropower facilities at an economic disadvantage. As policymakers consider ways to further reduce emissions from the electricity grid, it is critical that existing hydropower be treated on par with other renewable resources.

**Closing**

In closing, I would like to reiterate that conventional hydropower and pumped hydro have been and continue to be critical components of this country's energy infrastructure. And, more specifically, hydropower facilities are critical components of a resilient electricity grid. With the right regulatory policies and economic signals, hydropower will continue to enable the large-scale deployment of variable renewable energy resources.

I appreciate your time and look forward to your questions.

# Pumped Energy Storage: Vital to California's Renewable Energy Future

**Release: May 21, 2019** https://www.sdcwa.org/san-vicente-energy-storage-facility

## Executive Summary

California is a world leader in renewable energy. The state already sources nearly one-third of its power from renewables, mainly solar and wind. With recent legislation in place, renewable energy will increase to 60 percent or more by 2030. In tandem with renewable energy goals, the state is striving for 100 percent clean energy by 2045 to fight global warming. Shifting to more renewable energy requires forward thinking to balance supplies and demands while optimizing the use of these renewables for California ratepayers. Since renewable energy sources in California are largely from solar and wind, leveraging these resources requires additional electrical grid flexibility that can be best provided by energy storage.

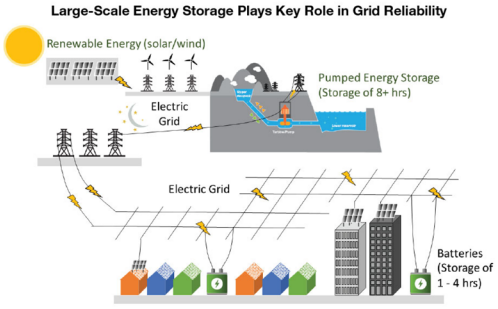
This renewable energy revolution is attractive for California, but it requires sustained support that will hinge on three factors. First, California must assure its ratepayers that a renewable grid will be cost-effective and reliable. Second, it must show that the renewable energy revolution will promote inclusive growth—with good jobs created in California and kept in California. And finally, it must ensure that the shift to renewables also delivers on the state's goals to fight climate change.

### Making Renewable Power a Reality

A massive shift to renewables will require new kinds of investments, markets, and business practices. Electric grids will need to be more flexible; new kinds of power supplies will help deliver energy flexibility when needed; and new pricing systems are needed to send clear signals to consumers so that they adjust their energy usage based on the times of day when electricity is most plentiful. What's unclear is how quickly or effectively all these changes will be realized and how these changes will align with what is best for California. For example, large electric grids across the Western U.S. can help import renewable electricity, but such investments won't create jobs from a renewable energy revolution in California.

**The central purpose of this paper is to articulate the opportunities and challenges for large-scale energy storage in the evolving California grid. In particular, this paper examines the need for a decisive push to deploy pumped energy storage. The lead times for such projects are long. Having projects operationally starting in the mid 2020s requires clearer policy and market signals today.**

**Solar and wind energy sources are variable; making best use of these resources requires additional electrical grid flexibility that can be best provided by energy storage.**




Energy generated by renewable sources, like wind and solar, can be captured by energy storage facilities and then distributed when needed. Batteries and pumped energy storage will provide the needed energy storage for both short-term needs (batteries, less than 4 hours) and long-duration needs (pumped energy storage, 8 hours or more).

While many pieces are needed in California's energy puzzle to make the shift to renewable power, there is one piece that will become pivotally important: energy storage. Perhaps more than anything else, energy storage will be the key to a successful California renewable energy revolution.

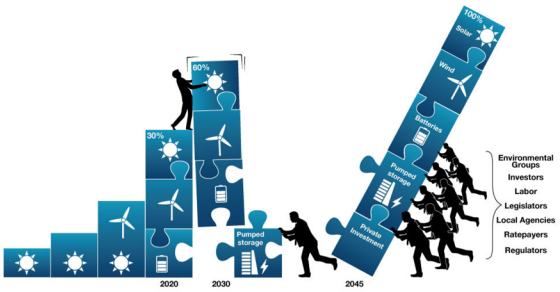
## The Pivotal Role of Large-Scale Energy Storage

Large-scale energy storage provides four interconnected services that are essential to facilitating California's big shift to renewables: 1) balancing generation with demand; 2) improving transmission efficiency; 3) providing electric grid stability; and 4) shifting power supply over long periods.

**While many pieces are needed in California's renewable energy puzzle, one piece that will become pivotal: energy storage.**

Large-scale energy storage is a highly cost-effective way to provide each of these services. Academic research and practical experience show that energy storage is vital to integrating renewable power in ways that keep the electric grid reliable. Energy storage can also help ensure that renewable power is used both day and night, making it easier to move beyond fossil fuels and help California meet its ambitious climate goals.

**Pumped Storage Elevates Renewables to 100%**




The target for renewable energy in California in 2030 is 60 percent – and large-scale energy storage in the form of pumped energy storage will play a pivotal role reaching that goal. State policymakers will need to work with local agencies and private investors to provide cost-effective energy while lowering risk to the electric grid.

## What Kind of Storage, How Much, and Where?

There are many different forms of energy storage ranging from very short periods to long durations (8+ hours and overnight, days, or longer). Batteries will play a role, but as demonstrated in this paper, their short storage duration (typically less than 2 hours) leaves the most cost-effective solutions for the largest and longest duration storage to pumped energy storage. This large-scale energy storage will be essential to demonstrating that California can move to 60% renewable power and approach the 100% mark. Many expert studies have been performed that demonstrate the value of pumped energy storage, including CAISO's Bulk Energy Storage Case Study, which found that a 500 megawatts (MW) pumped energy storage project in Southern California would provide ratepayers with a savings of up to $51M per year from improved efficiencies in system operation. Numerous studies show a rapidly rising need for large-scale, long duration energy storage in California (and the west) as the region moves rapidly to renewable power

while retiring or reducing its use of fossil fuel power plants. By contrast, the proven experience with battery systems is for much smaller projects with much shorter duration. Without significant new large-scale energy storage, California will likely be required to import more energy from other states, including potentially power generated with higher carbon emissions, such as coal and gas.

The State will be unable to meet its renewable and climate goals reliably without large-scale energy storage. Failure to invest adequately in pumped energy storage could also require more costly overbuilding of renewable energy generators and transmission lines, leading to even higher power and transmission charges in the State.

## Turning Pumped Energy Storage into Reality: Policy, Finance, and Investment

To be consistent with California's energy vision, active new policy support is needed to facilitate the development of pumped energy storage. Those policies should recognize the long lead times in building pumped energy storage projects (5 to 10 years). New policy efforts must begin now.

Among the needed actions are state-backed support for some early projects that would jump start investment in this proven technology. This support can demonstrate viable business models and investment strategies that will pave the way for more private sector-led projects in the future. The best early projects will be those that have low environmental footprints and are located close to renewable energy supplies and load centers. Care will be needed to ensure that financial support for such projects is aligned with the communities that gain most of the benefits.

New studies are also needed to understand the value of all forms of renewable energy and storage in the long-term evolution of California's energy system. Such detailed planning studies must look at the critical role for large-scale energy storage when, as is likely, other strategies for integrating renewables such as regional grid integration fall short. It should quantify the financial and environmental value to the state as investment in storage helps to ensure the shift to renewables and lower emissions is successful.

This white paper examines the complex and little understood challenges to achieving California's renewable energy and climate goals, and the critical role long-duration pumped energy storage will play in overcoming them.

### Key Facts

- **Renewable energy integration requires new thinking about energy grid operation.**
- **Large-scale energy storage is a vital part of renewable energy integration.**
- **Properly integrated into the electric grid, solar and wind can help California achieve its goal of deep cuts in greenhouse gas emissions.**
- **Pumped energy storage is a cost-effective, long-term energy storage solution with a proven track record.**
- **The State will be unable to meet its renewable and climate goals reliably without large-scale energy storage.**

# Pumped Energy Storage: Vital to California's Renewable Energy Future

**A White Paper by David G. Victor, PhD, et al**
**Release: May 21, 2019**

## The Big Picture

California is a world leader in renewable energy. Already, the state sources nearly one-third of its power from renewables, mainly solar and wind.[1] Under new legislation, renewables will rise to 60% of California's power supply by 2030 and then, by 2045, California will shift completely to 100% clean energy with no emissions of the gases that cause global warming.[2] In the history of electric power, no other major grid has seen such a massive transformation so quickly.

### Affordable and Reliable Energy

Making the clean energy transformation affordable and reliable will require new investments, policies, and planning. The wind does not always blow, and the sun does not always shine at times when electricity is needed the most.

One consequence of the variability in solar and wind generators is that they are often over-built to meet the need for power, leading at times to excess generation that requires grid operators to reduce output from other generators and curtail renewable energy. Without strategic planning and investment in storage, the amount of over-building and curtailment can rise sharply as excess generation events become more frequent. During these periods power prices can also swing wildly—leading even to negative prices. Other harmful consequences include under-utilization of expensive transmission lines and heavy reliance on natural gas power plants to fill in the gaps—a process that leads to emissions of carbon dioxide and other pollutants, which undermines the state's climate goals.

The telltale signs of this problem are already evident in California. In 2018, the California Independent System Operator (CAISO), the organization that runs the state electric grid, stopped or curtailed approximately 460,000 megawatt-hours (MWh) of renewable energy from being used on the electric grid.[3] That wasted energy is equal to about 80,000 households' total annual energy consumption.[4] It's also about equal to a $150 million solar project sitting idle all year.[5] These costs are vitally important to keep under control. One lesson from earlier energy crises is that Californians will support the shift to an all clean energy grid only if that isn't too costly and does not jeopardize reliability of electric power.

Curtailment is relatively small in the big picture. Of all the power generated for Californians, only about 0.2% is curtailed.[6] But that is because renewables, today, account for just one-third of California's power supply.[7] That situation is changing, with California planning to double the capacity of renewable power plants installed in just the next decade alone.[8] In 2018, CAISO had the single largest day of curtailment at about 10,000 megawatt-hours. On that day, April 28, the rate of curtailment (about 2%) was 10 times the annual average.[9] The California grid operator has warned that these curtailments are merely the start of a much bigger problem as the grid moves to higher fractions of renewable power.[10]

**Without more energy storage and new grid management, renewable energy will be costly to integrate fully into the grid. Making the clean energy transformation affordable and reliable will require new investments, policies, and planning.**

**A lesson learned from previous energy crises in California is that ratepayers will only support the shift to a 100% clean energy grid if isn't too costly and does not jeopardize reliability of electric power.**

**Recent California legislation to lower emission levels coincides with increases in renewable energy generation. To benefit from an increase in carbon-free renewable energy, it will be important to reduce curtailment of renewable energy through large-scale energy storage.**

Without more storage and better grid management, curtailment is poised to grow exponentially. One study, by the reputable Union of Concerned Scientists, projects curtailments climbing 70-fold as the fraction of renewables on the state grid rises from 33% to 50%.[11] As the grid moves to renewables there will always be some curtailment. The grid of the future will need the right mix of resources (generation, storage, transmission, and demand response) to deliver low carbon electricity at the lowest cost, while reducing curtailment to just the minimum level that is needed to keep the grid reliable.[12]

**Failure to make the needed investments in the California grid will jeopardize the State's ability to meet aggressive goals for renewables and emission controls.**

## Meeting the State's Environmental Goals

California is making the shift to renewables in tandem with other important energy goals, such as preserving the local environment and making deep cuts in emissions of carbon dioxide and the other pollutants that cause global warming.[13] The best scientific research summarized in the latest review by the Intergovernmental Panel on Climate Change (IPCC), shows that the most cost-effective strategies for achieving deep decarbonization will involve massive electrification.[14] It is easier to generate carbon-free power and then distribute the energy by wires than to manage the emissions from potentially millions of diffuse sources such as the engines in cars, hot water heaters, and industrial combustors in buildings and factories.

**Avoiding the 460,000 megawatt-hours of renewable power curtailed in 2018 would have cut about 720 million pounds of greenhouse gases—the equivalent of nearly one billion miles driven by the average American passenger car.**

California is following exactly this logic with its program to shift the state's major energy services to the grid, providing deep decarbonization through electrification. Those energy services include mobility (e.g., electric cars), heating (all electric), and industrial processes (shifting away from direct combustion of conventional fossil natural gas, such as for heating).[15] Current California law requires a 40% cut in emissions below 1990[16] levels by 2030, which is an ambitious goal since current emissions are similar to 1990 levels. A recent executive order would achieve net zero emissions across the whole California economy by 2045.[17]

Much of the political support for California's shift to renewable energy is rooted in the state being a leader in the effort to stop global warming. Delivering on that goal requires a well-managed grid so that renewables can help lower emissions in the most cost-effective way. Avoiding the 460,000 megawatt-hours of renewable power curtailed in 2018 would have cut about 720 million pounds of greenhouse gases—the equivalent of nearly 800 million miles driven by the average American passenger car.[18] In the real world, curtailment will never get to zero because in well-designed electric grids that integrate lots of renewables, a measure of curtailment is one of the many ways to help keep grids stable. Some plans for integrating renewable power into the California grid involve building larger regional grids across the entire west—an approach that could raise the risk that Californians import electricity generated by coal or gas from those other states. While that outcome is prohibited under Senate Bill 100, in the real world it is exceptionally difficult to monitor and enforce when electrons co-mingle on a single grid.[19]

## Making Sure Transformation of the Electric Grid Includes all Californians

Sustaining the political support needed for the renewable energy revolution requires paying close attention not just to costs but also other key elements of the political landscape.

The clean energy revolution must be inclusive. All communities must benefit. Investments need to flow to areas outside established wealthy urban zones so that the infrastructure needed for a renewable grid creates good paying jobs for Californians. A politically viable clean energy revolution will require addressing these concerns, such as articulated by the environmental justice community.

It is also vitally important that California's investment program include attention to the number and quality of jobs that it creates. Large infrastructure projects often generate important jobs. Focusing those jobs in the state, for Californians, is an important objective and vital to building and sustaining the broad political support needed for transformation and deep decarbonization of the power grid.

**All communities should benefit from the clean energy revolution. Investments need to flow to areas outside established wealthy urban zones so that the infrastructure needed for a renewable grid creates good paying jobs for Californians.**

## Assembling California's Energy Puzzle

Meeting the state's goals of creating a clean, cost effective and reliable grid for the benefit of all Californians is like composing the pieces of a giant puzzle. The pieces to the puzzle are represented by the various ways to generate, transmit, store, and use energy. Achieving the vision for a clean energy future will require massive changes in how California plans, builds, and operates its grid. Changes will be needed in all levels of the grid, from the state's electricity markets to how individuals use electricity. Today, nobody knows the exact size and shape of all the puzzle pieces. Some pieces, such as creating regional grids or shifting electricity consumption, may prove very hard to craft and implement in practice.

**Private investors responding to market signals alone won't deliver enough investment to meet the needs of the future electric grid without active policy measures to support large-scale energy storage projects that have long lead times for project implementation.**

Preparing for the real-world future requires options that we know work and will keep the grid reliable, such as large-scale energy storage, including pumped energy storage. Private investors responding to market signals won't deliver enough investment in these options, which is why active policy measures are needed to boost investment in these large-scale energy storage projects and address the long lead times. The project development period (between when a project is conceived and it is ready to serve Californians) is between 5 and 10 years. Active new policies are needed now to ensure pumped energy storage projects enter commercial operations when they will be critically needed.

Unfortunately, the electricity planning system in California is not, at present, designed to understand the magnitude of the renewable integration challenge. Nor is it able to assign the right value to large-scale, long-duration energy storage projects that will be needed to keep the grid reliable in the most cost-effective ways. Most planning takes its cue from the California Public Utilities Commission (CPUC) Integrated Resource Plan (IRP), an effort to develop a comprehensive plan for needed generation, storage, and other elements of the grid. CAISO looks to the IRP when doing its planning for the transmission grid. Many other vital policy makers also consult the IRP when checking to see if the state is on track to deliver its important energy, economic, and environmental goals. Currently, the IRP looks out only about one decade into the future and does not reflect the need for a longer term outlook to support the speed at which California is planning to reduce its emissions of warming gases. Furthermore, retirement scenarios for existing gas-fired generation plants are not fully taken into account in these plans. As a result, local capacity values of proposed storage projects are being estimated based on historical instead of potential future capacity needs; failing to provide the necessary market signals to trigger investment. To meet the State's plans for zero emissions by 2045, the power sector is expected to do the heavy lifting to cut emissions through the retirement of the fossil fuel fleet of generation because emissions from other sectors will be harder to limit.[20]

Those blind spots in the IRP process translate into blind spots in planning for the need to build large-scale energy storage facilities. These energy storage facilities are needed to store clean renewable power and integrate it into the grid while replacing the flexible generation now provided by fossil fuel generators. Other jurisdictions have a better grasp of how much storage they need by planning further into the future. For example, a recent Portland General IRP extended the planning out several decades to capture that market's similar shift to renewables and lower emissions.

It also extended the analysis of storage needs from 4 hours (typical of many power planning systems, including in California) to overnight storage of 8 hours and longer. From this more appropriate perspective, Portland General discovered the need to invest in much more large-scale, long-duration storage, including pumped energy storage facilities with 8 hours of capacity.[21]

### The Cost of Getting it Wrong

Failure to prepare for the State's renewable energy future could undermine the reliability of the California grid, which will harm consumers and undermine the State's economic competitiveness.[22] California's electricity costs, which are already among the five most costly in the nation, could rise sharply.[23] Failure to make the needed investments and changes in the California grid will also jeopardize the ability to meet aggressive goals for promoting renewables and reducing emissions. Under current state law, California's shift to renewables will slow down at 60% after 2030 unless there are demonstrated technologies and practices that make viable the push beyond 60% to 100% by 2045.[24]

## Four Ways to Keep the Grid Affordable, Clean and Reliable

The California Energy Commission (CEC), the CPUC, and CAISO have all been rightly focusing on the strategies needed to keep the grid affordable, clean, and reliable as the state shifts to renewables. CAISO, for example, has identified eight "solutions" that offer "promising concepts and technologies" that can help integrate renewables into the grid.[25] Here we take a step back from those details and focus on how grid operators and expert analysts around the world have analyzed and begun to solve the challenges of renewables integration.

**Maximizing renewable energy on the grid requires the use of four strategies:**

- **Price signals**
- **Interconnecting grids**
- **Flexible generation**
- **Energy storage**

In every electric power system that has shifted to renewables, grid operators have relied mainly on a mix of four different strategies for maximizing the use of renewables – price signals, interconnecting grids, flexible generation, and energy storage. The right mix of strategies depends on which options are available and their associated costs. California is learning that price signals, interconnecting grids, and flexible generation will be harder to use in practice. As those difficulties become more apparent large-scale energy storage becomes a particularly important option as the State tries to stay on track with its clean energy goals.

### 1. Price Signals:

Sending price signals to customers can enable them to adjust their behavior to reflect real time dynamics. When electricity is scarce, prices can rise and consumers will cut back on consumption. When supplies are flush, the opposite happens as prices tumble. "Time of use" rates – where electricity prices differ based on the time of the day – are one example of a price signal. California is already rapidly shifting to such an approach; starting in 2019, for example, the default rate charged for residential users will be "time of use," thanks to the installation of smart meters across the State.[26] Consumers can also participate in demand response programs, which incentivize them to reduce consumption during certain events.

**When electricity is scarce, prices can rise and consumers will cut back on consumption. The problem with demand response is that consumers can only adjust so much.**

The problem with demand response is that consumers can only adjust so much and exactly how much is very hard to pin down. The need for air conditioning, for example, increases in the late afternoon because people are returning to their homes when it is hot. This demand increase comes at exactly the same time as the sun is setting and solar output sharply declines each day. In contrast, businesses are open and consume more electricity during the day when people are awake and working. Energy experts are learning new ways to help customers become more responsive to power markets, but the overall conclusion from that work is that the total level of response is small.[27] This realization

– that demand response depends on human behavior, which may not always respond predictably to price signals: is particularly important when looking at the future of electric vehicles. Huge amounts of excess solar electricity can be used in the middle of the day, in theory, to charge electric vehicles on California roadways. Already 9% of new light duty vehicle sales are electric, and that fraction has been rising steadily. The problem is that a charging infrastructure for mid-day charging may not be available and many users will prefer to charge at home at night when they return from work even though power supplies from California's solar-dominated grid will be more scarce and costly.

There are good reasons to expect that analysts who are using models of ideal consumer behavior will over-estimate the amount of demand response that actual consumers display. Real world demand response depends on lots of factors that are hard to pin down in the models that analysts use to estimate demand response. Some examples of variables that influence the accuracy and predicatability include the detailed availiabity of infrastructure, how consumers process information, and how consumers make choices.

This unknown and often low level of demand responsiveness is one reason why grids that shift to renewables often have many periods when power prices are actually negative. In 2017, California had 110 hours of negative power prices—more than any other market in the world.[28] The full story behind negative power prices is complex. For example, in California these market conditions depend partly on precipitation in the hydroelectric system area, storage levels, and on subsidies that give power generators an incentive to keep producing even when the markets offer no reward. It is highly likely this problem will keep getting worse with the shift to more renewables.[29] Negative power prices are already leading to some market behaviors that aren't good for California's ratepayers and the state's vision of an affordable and sustainable power grid. For example, in March 2017, CAISO paid Arizona Public Utilities to take California's excess renewable energy for about $25 per megawatt hour. This is a great deal for Arizonans (who have invested less in renewables compared with California), but not for California's ratepayers.[30]

## 2. Interconnecting Grids:

A second strategy involves interconnecting grids. Academic studies of renewable power systems show that big shifts to renewables are almost always more cost-effective when they are combined with larger and more capable power grids.[31] That's because renewables are more variable in small geographical locations than when averaged over large areas. A cloud deck sitting over southern California will reduce solar output in that location. But if the grid has access to supplies in other areas, the average impact on renewable generation will be much less. This logic is part of the reason why China has invested to become the world leader in ultra-high voltage long distance power lines that make it possible to move power around the country where it is needed.[32] These power lines are costly, of course. For example, SDG&E's Sunrise Powerlink cost $16 million per mile to build. Australia and Germany—two other markets making a big shift to renewables—are also investing in much larger grid interconnections. The other large grid system making a comparable effort to shift toward renewables is Europe. Studies in Europe show that ideally configured grid systems could help integrate renewables by integrating more information about weather (e.g., wind speed and timing) into grid planning systems.[33]

The problem with the interconnecting grid strategy is that even massive grids that cover the entire western United States can't assure reliable energy all the time.[34] Massive interconnected grids are also politically very challenging to create. California already has some limited interconnections to other states, notably the hydro system in the Pacific Northwest. Legislation to allow much bigger interconnections and to operate the western grid as a single unit has been debated extensively in California and rejected every time. There are many concerns that grid interconnections will make it possible to "shuffle" contracts that provide new clean energy only on paper even as the western grid still relies on coal and gas.[35]

**Massive interconnected energy grids are politically challenging to create, could shift jobs out of California, and can't assure power will remain reliable all the time.**

While Californians have been concerned regarding an interconnected western grid, key stakeholders in other states are also politically concerned that California would dominate any regional grid, giving them less control over their own energy futures. These forces have created a key tension. On the one hand, the expert studies show that interconnections across the west will rise sharply in value as the region moves to renewables. However, at the same time grid interconnections could become more valuable technically, the political foundations for that strategy are eroding. One of those foundations is organized labor, which is concerned that grid interconnections will lead to a renewable future that is less inclusive of Californians as the beneficiaries. For example, by shifting jobs to infrastructure investments and new power plants in other states, California labor does not benefit because the California-based jobs necessary to achieve the state's ambitious renewable and zero-carbon emission goals would be effectively "exported" out of the state.

### 3. Flexible Generation:

Almost every power grid that has experienced an influx of renewable resources has responded by increasing its reliance on flexible generation. These plants can adjust their output up and down with the variation in renewable generators.[36] This has included increasing the quantity of natural gas and large-scale hydropower generation, as well as cycling power plants that were originally designed to run at maximum design capacity (known as "baseload" generators) up and down during the day in response to variability in the supply of renewables. Academics have quantified the benefits of these flexible supply options including the benefits of lowering the minimum output from power generators that are sitting nearly idle but ready to ramp up when needed. [37] For example, nuclear plants in the northeastern United States and on the French grid are ramping up and down due to the value of generation flexibility. [38]

**With reliable hydroelectric power already at its maximum and nuclear power phasing out, California has limited ability to rely on flexible generation that can adjust to compensate for the variability in renewable power and demand for energy.**

The problem with flexible generation is that the power plants needed to provide this service are not availalable. California will close its last nuclear plant in 2024 and there are no serious plans to build any more.

Flexible hydropower (hydroelectric energy production that can be ramped up and down with demands) is already used in California to its maximum, and the availability of these traditional hydroelectric facilities depends on seasonal fluctuations and can be reduced when precipitation is poor. Flexible hydropower from the Pacific Northwest may be shifted, increasingly, back to that region as they close more fossil plants and build more wind and solar.

**Flexible generation supports grid variability, but sufficient options to ramp power plants up and down must exist to make it a reality.**

Flexible fossil generators lead to higher emissions. Germany learned this lesson after its big investment in wind and solar did not lead to a significant reduction in national emissions. In California, the remaining flexible fossil fuel generators are all fired with natural gas. To meet its emission goals, California is trying to limit and perhaps even eliminate combustion of conventional natural gas—an action that could bring large political and technical tensions into the debate over the future of the grid.[39]

The future of fossil fuel power is shifting quickly in the west. Most planning systems have not yet caught up to the implications for the reliability of the grid, nor the need for new strategies to integrate renewables onto the grid. For example, a fresh analysis of reliability in the Pacific Northwest has shown that as fossil fuel generators are closed, there will be a much bigger need for technologies that can ramp up and down in line with variable power generators. This analysis specifically calls out "ultra-long duration electricity storage," of which pumped energy storage is the prime example.[40]

In the future, some renewable energy projects may operate in a hybrid mode—with onsite storage of heat or electricity—which could allow them to provide some of the functions of flexible generators. Under real world conditions, however, these so-called hybrid energy systems have had many problems and may not offer the longer-term flexibility and ramping needed for a grid as high levels of renewables are brought online.

### 4. Energy Storage:

**Challenges with other renewable integration strategies leave large-scale energy storage as the central option to meet California's renewable energy goals.**

Difficulties with these first three strategies leaves a major role for energy storage. The energy storage systems that will be needed come in many forms. Some will be smaller, decentralized battery systems, located at individual residences along with commercial and industrial (C&I) facilities. Indeed, California is already deploying many of these systems, but not necessarily with the goal of improving operations of the electric grid. Rather, these systems are being procured more in response to local incentives, such as the desire of C&I customers to shift their peak demand usage and reduce electricity bills. New kinds of power plants will also embed energy storage into their generators to help make output smoother and more controllable at times when power is needed. All these energy storage systems will play a role, but the most important foundation for an affordable, reliable and clean electricity system will be large-scale energy storage systems directly connected to the electric grid that can respond to the variability of renewable resources and consumer needs.

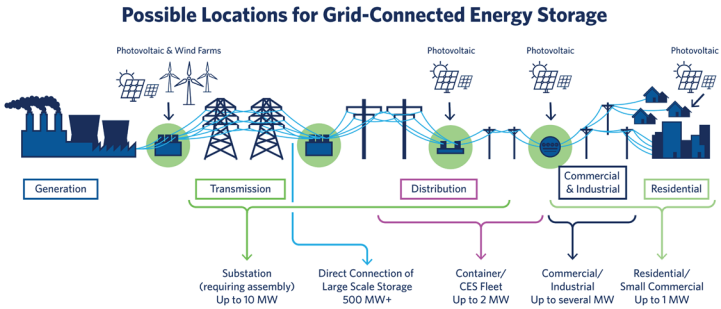



Figure 1 – Figure 1 is a schematic of the electrical grid indicating the different roles various technologies play in the energy storage arena. Multiple energy storage technologies will likely be needed to support California's renewable and clean energy goals.

## The Pivotal Role for Large-Scale Energy Storage

Large-scale energy storage provides four interrelated services that are essential to keeping the lights on, while facilitating a big shift to renewables including:

- Balancing generation and demand
- Improving transmission efficiency
- Providing electric grid stability
- Shifting power supply over long periods

**Pumped storage provides benefits beyond energy storage, including services that help make the grid reliable and avoid the need for costly transmission upgrades.**

### Balancing Generation and Demand

**Large-scale energy storage provides multiple benefits needed for a reliable and stable electric grid.**

Large-scale energy storage allows large quantities of renewable energy to be saved, thereby reducing the need for curtailment. Typically, the large-scale energy storage systems that are in operation charge and discharge one or two times per day. The pumped energy storage systems operating elsewhere in the United States and the large pumped energy storage systems in Spain are examples of systems operating in this manner. Integrated with solar generators, as in Spain, pumped energy storage systems recharge during the mid-day peak of output and, often, also at night when power demand is low and there is excess power on the electric grid. The systems discharge twice daily — once during the morning rise in energy demand (before the rising sun raises solar output) and then again in the evening as the sun sets and net energy demand rises. Therefore, one important function of large-scale energy storage is measured by its ability to store and dispatch energy throughout the day to balance generation with demand.

### Improved Transmission Efficiency

Second, large-scale energy storage makes it possible to use existing transmission lines more completely, avoiding the cost and political difficulty of building new transmission systems. Under CAISO, California has already invested in some relatively small energy storage systems that delay or avoid more costly transmission upgrades. CAISO, for example, has already approved several small (few megawatts to tens of megawatts) energy storage systems based on this logic.[41] Recent guidance from the Federal Energy Regulatory Commission (FERC)[42] could make more use of energy storage in this way.

The same logic is now leading to some energy storage systems that can replace retiring gas-fired power plants. CAISO has been exploring a much larger role for energy storage that could lead some large-scale storage being treated as an integral part of the state's reliable transmission system.[43] But delivering on a full new plan for integrating energy storage and transmission has proved technically and politically difficult, which is evidence that even when ideal policy outcomes can be imagined, they can be hard to put into practice. Which is why planning for California's carbon-free future requires focusing heavily on options that are known to be reliable and scalable.

### Providing Electric Grid Stability

A third function of large-scale energy storage is assuring stability of the electric grid. Managing an electric grid requires keeping voltage and frequency of the entire system within extremely narrow tolerances. Imbalances, when they occur, can damage sensitive equipment and even destabilize the electric grid. Australia experienced this when extreme storms damaged power lines in 2016 and problems managing renewable wind resources amplified the problem. One of many remedies to electric grid instability was investment in a large battery storage project to provide voltage support across Australia's largest two grids. At the time, this

**Pumped storage provides large amounts of energy stored as inertia in the spinning rotors that provide grid stability needed when electric grid conditions change quickly.**

facility was the world's largest installed battery (100 MW). Periodically, massive electric grid failures are a reminder of why electric grid reliability is so important. For example, the world's largest electric grid failure in India (over two days in 2012) left 700 million people without power.[44]

Traditionally, operators have kept the electric grid stable by drawing on large amounts of energy stored as inertia in the spinning rotors of conventional generators like hydroelectric machines. These are known as "primary services" because they are are an intrinsic, physical part of a conventional grid. They work in tandem with a host of "ancillary services," which are an array of market-based products like automatic generation control (AGC), black start, and voltage support. Physically, many of these primary services have come from power generators that have large spinning turbines that can provide stability even when electric grid conditions change quickly. Spinning mass provides inertia, a form of energy storage, and primary voltage support through automatic voltage regulation (AVR's), Power System Stabilizers (PSS) and primary frequency support through governors. Unlike ancillary services, which are signals for response that the grid operator (CAISO in California) sends several seconds after some event that creates instability on the grid has occurred, the primary response from energy stored in the spinning rotor and primary voltage and frequency response is immediate. The value of both these services—primary and ancillary—is huge in assuring stability of the grid. However, these services today are largely supplied by conventional generators that already exist on the grid, and thus there isn't much of a formal market that actually reveals this value. The absence of those full market signals is emerging as a major challenge in the shift to renewable power—where the energy systems do not rely on spinning turbines, but are electronics such as inverters that convert DC current (from solar panels and batteries) into AC for the grid.

New power electronics, including smarter inverters, make it possible to provide some ancillary services without spinning turbines. In Australia, for example, a project that at the time became the world's largest installed battery (100 MW) has helped provide voltage support for an electric grid that otherwise would have difficulty integrating renewables as coal-fired plants and their large spinning turbines were being retired in that country. Such illustrations are encouraging, but by themselves they do not offer a roadmap for assuring grid reliability for at least two reasons. One is that in the real world the performance of these electronic systems has been uneven. For example, during fires in 2016 and 2017 inverter-based technologies were unable to provide the services needed to assure reliability in California—leading the national authority that oversees electric grid reliability to issue alerts to CAISO.[45] Second, while primary and ancillary services create value for society as a whole, the efforts to create special markets for ancillary services that can encourage private investors to build the needed systems remain immature. So far, these markets are rarely lucrative enough on their own to make large-scale private sector solutions to electric grid stability feasible.

A big shift to renewables is likely to create a much larger need for the services required to keep the grid reliable, such as the systems that manage the frequency and voltage of the electricity on the grid.[46] For electric grids that are making the shift to renewables quickly, the need for primary response services may rise much faster than markets can keep up. For example, in 2018, comparisons across different days reveals how a larger role for renewables can create highly variable electric grid conditions that managers must handle to keep the lights on reliably. Figure 2 shows two typical days in 2018 on the California electric grid—one in late May (top) and the other in July (bottom). For each, the top line of the chart shows total demand for power (much higher in hot July than cooler May) and the bottom line shows net demand that remains after available renewables have served the load. The bottom line is known, famously, as California's "duck curve." What is interesting is the speed at which the lower line rises in the late afternoon as the sun sets but energy demand keeps rising. Today we typically see between 5,000 to 12,000 MW changes in just three hours. The net demand at night remains high as people keep using electricity even as solar output trends to zero.

**A big shift to renewables is likely to create a much larger need for the services required to keep the grid reliable, such as the systems that manage the frequency and voltage of the electricity on the grid.**

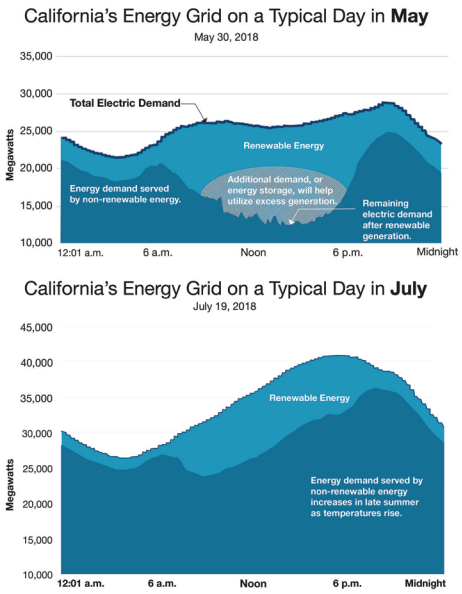



Figure 2 – California's Grid on a typical day in May (top, 30 May 2018) and July (bottom, 19 July 2018). Source: CAISO.

## Shifting Power Supply Over Long Periods

A fourth function of large-scale energy storage, which is expected to increase in importance, is the ability to shift power supplies over longer time horizons, such as several days. The need to start thinking about long duration energy storage is revealed by looking at how California curtails its renewables. Nearly all curtailment happens in the late spring. Figure 3 shows monthly data from CAISO. Looking closely at the data shows large day-to-day variability. Big reductions in wasted renewable energy can be achieved if there is the capacity to store that energy over several days. Some studies suggest that an all-renewables grid will need the capacity to arbitrage energy over even longer time periods—such as months to seasons.[47]

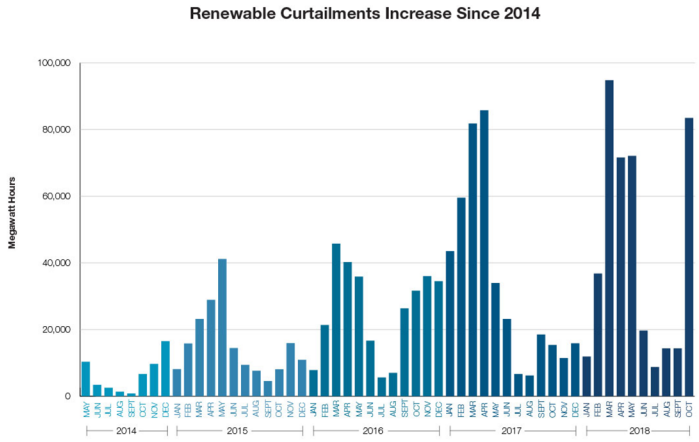



Figure 3: Curtailments, Month-by-month since 2014. The chart here shows monthly curtailments, which is the available renewable power that was rejected by grid operators, measured in Megawatt-hours. Source: CAISO.

At present, California obtains this multiday energy storage by relying on hydropower in the Pacific Northwest and on fossil fuel generators that can be turned on and off as needed. With decarbonization of the electric grid, the option of using fossil generators will decline. The existing hydro systems in the Pacific Northwest, along with the electric grid interconnections into that system, are limited, and hydro capacity itself can vary widely from year to year with variations in rainfall and other environmental constraints. While there have been many visions for a rapid shift to an all solar and wind power grid, one of the central critiques of those visions is that they are often unrealistic in their assumptions about the need for massive multi-day, multi-week and inter-seasonal energy storage of electricity.[48]

**To meet California's renewable energy goals, it's necessary to shift supplies from when energy is generated to when it is needed.**

No country or market has yet to figure out how to invest in large-scale long-duration energy storage systems that could provide this fourth function. None of the big battery systems presently in operation or being contemplated can do that. For example, Australia's 100 MW battery has a less than two-hour capacity, which is why Australia is now considering whether to build 2,000 MW of reliable pumped energy storage integrated into the country's existing hydroelectric system. This will create the ability to store massive amounts of energy for weeks to months.

**While batteries provide short-duration energy storage, pumped storage is needed to provide long duration energy storage (8 hours or more). That allows for increases in the amount of renewable energy that is put on the grid.**

California already has some experience with pumped storage at eight locations. However, nearly all of these projects were built in an earlier era under a different policy environment. Moreover, most were built for purposes other than large scale storage of energy, such as to facilitate water supply. A lot more large-scale energy storage will be needed—especially located close to renewable energy facilities

and load centers. In Spain, the country's massive deployment of solar and wind power has run in tandem with building about 5,500 MW of pumped energy storage for a grid with a peak power consumption similar to California (about 43,000 MW).[49] Even with such a high investment in pumped storage there will be a need for more in the future. At present, about one-quarter of Spain's electricity comes from wind and solar and, like California, Spanish policy makers are pushing ahead to 100% renewables.[50]

## What Kind of Energy Storage, How Much, and Where?

Since energy storage must perform many different functions, energy storage systems will be deployed in many different forms with different technologies and attributes. The different types of storage are also likely to require different market and funding mechanisms to encourage their development. Conceptually, the many different types of energy storage are shown on Figure 4. These include systems that operate over short time periods—nanoseconds to seconds and minutes—with a relatively small power rating. Those are shown in the lower left corner and include supercapacitors and battery systems that smooth out power flow and keep the electric grid reliable. At the opposite extreme are large-scale, longer-duration energy storage systems such as pumped energy storage—hundreds of minutes to hours of storage. The rest of this white paper will focus on those systems.

**Batteries and pumped storage will be soon needed to provide large-scale energy storage to meet the escalating challenges associated with increasing renewable curtailment.**

### A Snapshot of Many Types of Energy Storage Technologies

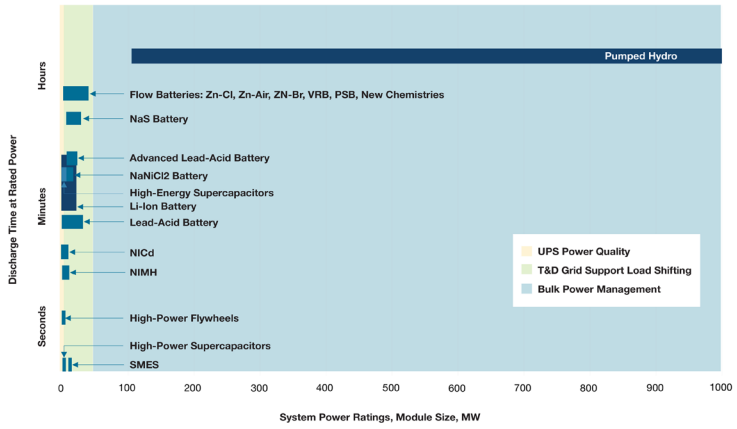



Figure 4: The "What": Many Different Types of Storage and Services. The figure shows power rating (horizontal axis) and time horizon for services (vertical axis). Various types of battery systems provide similar functions ("Li-Ion" systems are the most widely discussed battery systems today, but Nickel-Cadmium (NiCd), Nickel Metal Hydride (NiMH) and lead acid systems are earlier generation variants). There are many kinds of "flow batteries" that use large vats of liquid for storage and thus are easier to scale to larger size and long duration. Pumped hydro is at the top; other large-scale storage systems include compressed air energy storage (CAES) which so far has proved expensive to scale. Source: adapted from 2014 DOE/EPRI storage roadmap.[51]

California is moving so quickly to renewables that nobody, at present, knows exactly how much large-scale storage will be needed nor exactly where it will be needed. What is clear is that the needs are poised to rise quickly and exponentially. A series of studies (some by California government agencies and some by independent laboratories and academics) can help to provide some answers.

The exact need for large-scale energy storage will depend on progress on the other fronts that can help integrate renewables. For example, if progress on electric grid interconnectedness and demand response remain slow, as is likely, even more energy storage will be needed. Moreover, the best location for storage resources will be located close to the large renewable generators or the existing power lines that bring that generation to places where power is used. As a practical matter that means located along the state's power corridors and close to load, such as near the cities in Southern California and in the broader Bay Area.

**The best locations for energy storage will be close to renewable energy sources and power loads—such as cities in Southern California and the Bay Area.**

CAISO has sponsored an illustrative study on these questions. Published in November 2015, the CAISO Bulk [large-scale] Energy Storage Case Study (BESCS) specifically looked at the value of building a 500 MW pumped storage project in southern California. The study found that such a project could avoid the need for 348 MW of solar overbuild or 179 MW of wind overbuild. This project, over its lifetime, would avoid nearly 4,000 gigawatt hours (GWh) of curtailment due to a lesser need to over-build solar. Compared with a grid that didn't have the 500 MW pumped storage project, the BESCS analysis showed that the savings would amount to $36M-$51M per year due to more efficient system operation. Those savings would accrue after the full costs of building the pumped energy storage system were factored into the analysis. This study demonstrated a massive increase in the value, such as grid stability and less curtailment of renewables, that society gets from a pumped energy system. All told, CAISO concluded that large storage projects of this type would "reduce curtailment, CO2 emission, production costs, and the overbuild of renewables".

**According to a CAISO Large-Scale Energy Storage Case Study, a 500 MW pumped storage project in Southern California would provide a savings of $36M to $51M per year due to improved efficiencies in system operation.**

Studies from other organizations have analyzed the question of "how much" energy storage is needed using different methods of analysis and have arrived at comparable conclusions. That is, a significant amount of large-scale energy storage will be needed and energy storage projects, with the right market rules and policy incentives, add value. Notably, a 2016 study by the National Renewable Energy Laboratory (NREL) finds that the storage already being installed is sufficient to allow up to 40% solar photovoltaic (PV) generation on the California grid, but that the need for storage rises exponentially as solar rises to higher proportions of the generation mix. Another 15 Gigawatts of energy storage would need to be built by 2030 to allow just an extra 10% of power to come from solar sources.

**Another 15 gigawatts of energy storage will be needed by 2030 to allow just 10% more power to come from solar sources.**

The NREL study adopted optimistic assumptions about the flexibility of the electric grid, with robust interconnections and a shift of one-quarter of California's light duty passenger cars to electric vehicles, most of which are charged optimally (during mid-day) to take in excess electricity from the grid. But if the electric grid proves to be less flexible, then storage needs are even higher—for example, if electric vehicles aren't charged optimally but instead are charged when drivers get home at night because that is convenient.[52] The study is a warning sign about the risks to the reliability of the electric grid from inadequate investment in the energy storage capabilities that will be needed quickly and how much more will be needed if the California electric grid falls short of what engineers would like to have as an optimal electric grid. Of course, "energy storage" comes in many different forms, as discussed already in Figure 4, but

the NREL team focused on the role of long-term energy storage (systems sized for 8 hours), which is typical of large pumped energy storage systems. Indeed, there is no other technology proven with extensive experience that can provide such large-scale and long-duration storage.

Of course, there are many different visions for the future of energy storage. Some reporting and analysis suggests less energy storage will be needed and that batteries can fully do the job.[53] But these studies tend to be based on highly optimistic assumptions, with optimal implementation and operation of flexible generation resources, regional electric grid interconnectedness, and lots of demand response, such as optimal electric vehicle charging, are all optimally implemented and operated. In the real world, where that doesn't happen, large-scale energy storage offers Californians a compelling option that can ensure cost-effective, reliable and clean energy supply.

**In the real world, where many strategies for integrating renewables don't fully materialize, large-scale energy storage offers Californians a compelling option that can ensure cost-effective, reliable and clean energy supply.**

## The Special Value of Pumped Energy Storage: Comparisons with Batteries

The rapidly rising need for large-scale storage requires clear thinking about the cost and flexibility of the options for providing this vital service. With the continued improvement in battery technology in the news, one view that has emerged is that batteries can "do it all." The reality is different. There are roles for batteries and pumped energy storage (and perhaps other large-scale storage technologies) to provide services in tandem.

The key question that must be answered is for each storage service, which options are least costly and offer the greatest value? Here we offer some answers by comparing financial analyses of pumped storage (PS) and battery energy storage systems (BESS). Our analysis is financial in orientation. Rather than just focusing on the engineering attributes of the different technologies, we must include important details such as the following:

- How will PS and BESS projects be financed (debt and equity)?
- What are the borrowing costs and equity returns?
- What project risks are there?
- What are the time horizons for the projects?
- What are the tax and profit implications?

A successful strategy for building large-scale storage in California must address financial realities and cost-effectiveness that will be central to whether projects can attract capital from private and public sector entities.

A perfect comparison between pumped storage and batteries in providing the service of large-scale storage is impossible at this stage. That's because while there are many pumped storage projects in the world with long histories of operations revealing key facts such as capital costs and reliability, there are no similar battery projects. Some large battery projects are entering service, but typically these are still much smaller than pumped storage facilities. The full-service lifetime of battery projects is unknown, and essentially all warranties and regulatory approvals do not extend beyond 20 years. Typical financial and

**A successful strategy for building large-scale energy storage in California must address financial realities and can attract capital from private and public sector entities.**

**California's rapid increase in renewables energy creates an urgent need for a big increase in large-scale, long-duration, energy storage services. Many pumped storage projects in other markets offer models for that service, but there is no comparable experience with batteries.**

**The timeframe for assessing energy storage costs matters. Projects that have a longer useful life trend towards lower costs for ratepayers.**

engineering time horizons for pumped storage projects are 40 years and beyond. Finally, most battery projects have useful storage durations of less than 2 hours (a few offer longer, four hour storage service). Pumped storage systems are designed for longer storage (typically 8 hours or more) and are easier to scale beyond that duration.

These untested comparisons are a central finding of this white paper. While one can imagine battery configurations that are comparable with large-scale, long duration storage services offered by pumped storage, it is not possible to find real world analogs to those projects to understand their financial and technical attributes, including their reliability. California's rapid shift to renewables guarantees the urgent need for a big increase in large-scale, long duration storage services. Many such pumped storage projects in other markets offer models for that service, but there is no analogous experience with batteries. Mindful of these facts, we offer our financial comparisons using the best data. We document our assumptions in the footnotes and in tables in the Appendix.

## Levelized Cost of Storage

Our analysis is in two steps. First, we calculate the "levelized cost of storage (LCOS)" for a large pumped storage project comparable to the one that CAISO analyzed, as noted above: 500 MW of storage over 8 hours. Multiplying those two numbers together provides the total volume of usable storage for such a project: 4000 MWh. LCOS is a widely used calculation that estimates the constant revenue "levelized" stream in $/MWh over the life of the project needed to finance a project, pays all operational costs, services debt, and allows a reasonable return for equity investors.

We project the capital cost for the year 2026 at about $1.9 billion, or about $475,000 per MWh of storage capacity.[54] The year 2026 represents when such a project could reliably be operational if a clear signal is given soon. As we will show, when the long useful project life is incorporated into the analysis, pumped storage projects have a very attractive cost per MWh, even lower than battery projects. We also estimate the cost of pumping energy based on cycle efficiency, O&M costs, debt service, taxes on project profits (28%), and a host of other factors.[55] Any such analysis necessarily involves a swarm of assumptions, but through extensive sensitivity analysis we have identified one of the most important assumption is capital cost. The costs we assume are based on extensive experience building comparable civil works. These costs also anticipate a project designed with a low environmental footprint, one that uses an existing large reservoir (there are many in California) and builds a smaller new upper reservoir.

**While the cost per MWh of storage capacity is higher for pumped storage than for batteries, the longer useful lifetime of pumped storage projects more than compensates for this by lowering the levelized cost of storage. The overall costs for pumped storage are far lower.**

**All U.S. pumped storage projects that have completed or are nearing completion of their original FERC license term, have or will be re-licensed, demonstrating their value.**

**Pumped storage systems have well-known costs and performance, and they are highly cost-effective for large-scale, long-duration energy storage.**

Figure 5 shows the LCOS for pumped storage over three different time horizons. First is 40 years, the minimum practical time horizon for a California pumped storage project, the duration that is widely used in the industry. This time horizon is long enough that the fuller value of capital-intensive pumped storage investments can be amortized, offering the benefit of large-scale storage services at costs that are beneficial to ratepayers. Second is 50 years, which is the longest operating license for pumped storage facilities offered by FERC today. The third is beyond 50 years. This time horizon represents a project that is upgraded at modest cost around year 50 and then relicensed for another 50 years. This scenario represents a practice already widespread for large hydropower facilities and is entirely plausible for a California pumped storage project.[56] Indeed, all U.S. pumped storage projects that have completed or are nearing their original FERC license terms have or will be re-licensed.

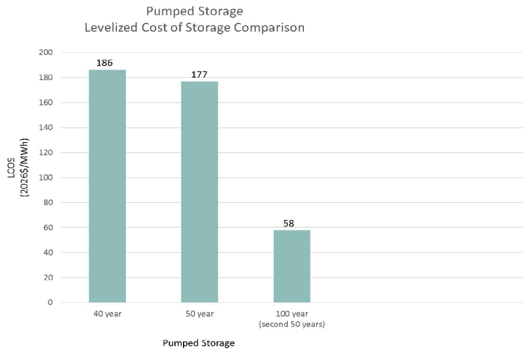



Figure 5: Pumped Storage cost per megawatt hour decline as the project life extends. Pumped storage projects operate over many years, making them a highly cost competitive options for large-scale energy storage. (sources: see Appendix.)

**Extending the cost analysis of pumped storage projects from 50 years to 100 years reveals a significant drop in cost. The LCOS for the second 50 years of a 100 year project, when the original costs are all paid off, is almost half the cost of the first 50 years.**

A central insight from this analysis is that the time horizon matters—longer time horizons mean lower costs for ratepayers. Extending from 40 years to 50 years lowers the cost of storage modestly (about 4%). The savings from an extra decade for amortizing the capital cost are offset, in part, by compounding inflation in operation and maintenance costs.[57] Extending from 50 years to 100 years sees a massive drop in cost. The LCOS for the second 50 years of a 100 year project, when the original costs are all paid off, is almost half the cost of the first 50 years.[58]

## Battery Comparison

In the second step of our analysis we compared pumped storage with battery systems. Here we rely on published, authoritative studies by other experts who are tracking the battery industry closely. In particular, we focus on Lazard, which publishes a widely used and regularly updated survey, and the Electric Power Research Institute (EPRI), the most authoritative research arm of the electric power industry.

**Reputable studies of battery systems show that huge uncertainties remain to determine the real cost of battery storage systems. Those unknowns are particularly large for battery systems deployed in ways that are unfamiliar and untested—especially for large-scale, long-duration batteries beyond 2 or 4 hours.**

Figure 6 shows Lazard's estimates for Lithium-based battery projects that are designed to operate over typical warranty periods (20 years) and sized at 4 hours storage duration, which is already on the outer edge of commercial experience (most of which focuses on shorter duration). Compared with pumped storage, the capital cost for these projects is lower ($285,000/MWh to $452,000/MWh), but that cost must be paid back more rapidly because the lifetime of these projects is shorter. The overall effect is to make batteries more expensive than pumped storage when those costs are levelized over the relevant time period. We underscore that there remains substantial uncertainty especially for battery projects because nearly all of the operational experience with these technologies is for much smaller systems operating over shorter time horizons (typically 1-2 years). Efforts to reflect some of those uncertainties, as illustrated with Lazard's low and high numbers on Figure 6, suggest that batteries will remain overall more expensive than pumped storage—possibly 50% more expensive than pumped storage.[59]

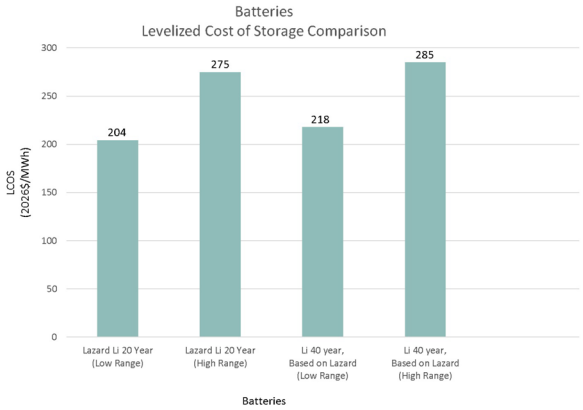



Figure 6: Lazard and EPRI have highly credible battery analyses that were used to support the cost per megawatt hour of batteries used in this analysis. (Sources: see Appendix.)

One of the many strengths of the Lazard analysis is that it uses the same parameters that we include in our analysis of pumped storage. The Lazard analysis includes pumping costs (charging) and is attentive to debt/equity ratios, costs of capital and equity return, and includes taxation. Such comparisons must be made, of course, with the many remaining differences in mind. For example, today's battery projects are typically structured very differently from pumped storage projects because the technology is newer, business models are still evolving, and low-risk long-term contracts are therefore less widely used. For these reasons, today's battery projects typically involve more risk and thus a greater role for equity (and higher costs of raising capital).[60]

**The battery levelized cost of storage shown in this study may be optimistic given the unknowns associated with the lifetimes of battery systems, the duration of storage, and vital operational issues such as the depth at which batteries can discharge without suffering costly damage.**

There are some key differences between our evaluation of pumped storage and Lazard's reputable study of battery projects that point in the opposite direction. In at least two ways, the data shown from Lazard understates the cost of battery projects that provide bulk energy storage services comparable with pumped storage. Two of the largest items are the duration of storage and time horizon for projects. Regarding duration, the data shown on Figure 6, taken directly from Lazard, are for 4 hour projects using the rated storage capacity and duration of battery systems. In the real world, the useful storage in a battery system is often lower than the rated capacity because today's battery systems often suffer damage at full discharge. A recent project in Southern California, for example, purchased a 50MW rated battery system to yield reliably only 20MW of capacity. We ignored these real-world differences between rated and useful capacity, a phenomenon rarely observed with pumped storage projects. Indeed, most studies do not distinguish between the purchased and useful size of battery projects, with the result that most existing studies may underestimate the actual costs of these battery systems when deployed under real-world conditions. For instance,

Lazard assumes a 100 percent battery discharge. This means that the cost data on Figure 6 could be quite optimistic about real world costs of battery systems.[61]

Because time horizon is so important for understanding the financial analysis of large-scale energy storage, we can't ignore those differences. Pumped storage projects offer value at 40 years and beyond whereas the Lazard analysis on Figure 6 is only for 20 years and essentially all other reputable studies of battery systems have a similar time horizon. To indicate the effects of building a 40-year battery project we extend the Lazard analysis. This analysis is based on the lowest-cost assumptions for battery modules and other costs of a BESS. We estimate the cost of replacing the battery modules as they wear out. The replacement effort in this analysis takes place over 5 years starting at year 15. Because battery technologies are getting better over time, we assume that the batteries themselves are one-third cheaper starting in year 15 which is consistent with industry estimates. Even though batteries are much cheaper in the future, this 40-year time horizon leads to a more expensive battery project. This is because even as the capital costs from batteries decline as a portion of the overall project cost, the inflation on other elements of the system more than offsets the improvement in battery replacement costs.

To complement the Lazard analysis, we make some comparisons between Lazard's analysis and work by the EPRI. While the EPRI analysis does not focus squarely on the financial engineering of these projects, it is exceptional on the physical engineering and performance of these projects, including factors such as real depth of discharge and real-world costs for all the balance of system technologies needed for an operational battery system. The EPRI analysis is more conservative than Lazard and other studies in an effort to reflect the reality that there is limited experience with battery projects at this scale. It also has two other attributes that help round out our evaluation. First, it looks at battery technologies over longer storage periods (8 hours)—a difficult and somewhat speculative effort because the operational experience of battery systems is so much shorter. Second, it includes a detailed estimate of the end-of-life recycling and disposal costs for battery systems, which can be significant. These factors lead EPRI, generally, to assume that the capital cost for battery systems (which, like pumped storage, are the largest single component of LCOS) is about 10% higher than assumed by Lazard.[62]

## The Big Picture: Comparing Pumped Storage and Battery Systems

Looking across all the reputable studies of battery systems it is clear that significant uncertainties remain around the real cost of battery storage systems.[63] Those unknowns are particularly large for battery systems deployed in ways that are unfamiliar and untested—especially for large-scale, long-duration storage.

This analysis underscores that pumped storage systems have well-understood costs and performance and are highly cost-effective for large-scale, long-duration energy storage. California will need exactly those services if it is to integrate massive amounts of renewables into the grid. While it is hard to pin down exactly when those storage services will be needed, it is plausible they will rise rapidly in the 2020s and scale roughly in exponential fashion. Understanding that timing and scale—and the costs of delay—is a study item we discuss in more detail below.

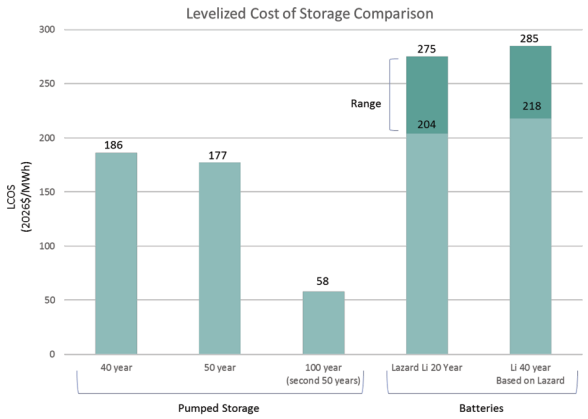



Figure 7: When evaluating large-scale energy storage options, the two most mature technologies demonstrate favorable options to cost effectively integrate renewable energy on the California grid. With the long, reliable project life of pumped storage, investments today will offer greater savings for future generations. (Sources: combination of Figures 5 and 6).

Finally, we close our financial analysis by reiterating that these kinds of comparisons hinge on many uncertainties and assumptions. By far, the most important sensitivity is capital cost. Reducing the capital cost of a pumped storage project by 10% would lower the LCOS for a 40-year project from $184/MWh to $173/MWh. Policy attention should be focused on ways to improve these high leverage variables, such as the capital cost for building large-scale energy storage. Policy initiatives that create more certainty for investors and that lower risk for early projects are examples of approaches that could reduce capital cost along with the debt and equity returns needed to finance that expenditure.

**Policy attention should be focused on ways to improve high leverage variables, such as the capital cost for building large-scale energy storage.**

## Other Benefits of Large-Scale Energy Storage

The analysis we present here focuses on large-scale energy storage—that is, the ability to "move" electricity from periods when it is in excess (e.g., noon on sunny days) to other times of the day or week when renewable generators can't meet demand (e.g., at night or on cloudy days). A full-blown comparison of pumped storage and battery systems would also look at the relative cost and performance of these storage systems in providing a variety of ancillary services. Some of those services are equally well served by pumped storage and batteries. For example, both types of technology can provide voltage support, a key service for keeping the grid reliable. There are good reasons to think that pumped storage systems are better at keeping grid frequency stable at 60 cycles per second. In the past, the spinning turbines at central station power plants, including hydroelectric plants, provided this vital service. These plants used inertia—stored as steam, water, and spinning turbines—in response to changes in demand. Simple governor controls sensed minute changes in frequency and adjusted output to maintain frequency within an extremely high level of

accuracy that is critical to reliability and quality of electricity on the grid. Increasingly, users of electricity require clean and reliable power for advanced electronics and other sensitive equipment.

The shift to renewable, distributed, and battery technologies has meant that the grid is less able to tap physical inertia and must rely on digital control systems. Utilities, system operators, and the FERC are increasingly concerned about the future where frequency control relies on digital equipment. Those same concerns apply to large-scale battery storage systems—which will rely on digital controls—and suggest that reliable and accurate frequency control will remain a major advantage of pumped storage systems that, like other large generators, use spinning turbines and physical storage of water.

## Turning Pumped Energy Storage into Reality: Policy, Finance, and Investment

Today's markets and regulatory systems do not create incentives needed for investors to build these pumped energy storage systems. Despite the high social value from pumped storage for California (a value that will rise sharply over the next decade), the attributes of the technology and California's power markets don't yet create the right incentives for investors to put capital into pumped energy storage. At present, the incentives to deploy energy storage are much weaker than the expected needs for energy storage in the next decade and beyond. Where rules do exist, they do not allow large-scale pumped energy storage to compete.[64]

**Without more energy storage, California may be forced to import more electricity from other states, including power from high carbon sources such as coal or gas.**

Failure to create the right incentives could undermine California's efforts to create an affordable, reliable, and clean electric power system. Without more energy storage, California may be required to import more electricity from other states, including potentially power generated with higher carbon emissions, such as from coal or gas. The state would be required to keep more gas-fired generators operational in-state to ensure reliability of the electric grid. With more gas will come more emissions. Failure to create incentives, specifically for pumped energy storage, could foreclose investment in the most cost-effective option that creates special advantages. Jobs created for construction of a pumped energy storage project will be more lucrative and longer-lived than those needed to clear and wire staging pads for BESS. Properly sited and configured, large-scale energy storage with spinning turbines can help optimize California's transmission system, including the Sunrise Powerlink that brings clean solar power into southern California. Pumped energy storage is a proven technology with a long track record. It is resistant to types of natural disasters like fires and earthquakes and can provide relief when blackouts occur. The viability of heat-sensitive BESS in fire-prone areas remains unknown. The 40+ year lifetime of pumped energy storage projects helps anchor the state's long-term commitment to renewables.

The advantages of pumped energy storage are becoming clearer, as is the diagnosis of why the state, so far, has not created the right incentives for private investments in pumped energy storage. The central problem is the difficulty under current market and policy arrangements to develop reliable long-term contracts for storage services. This includes energy services agreements and other arrangements that would be needed to arrange long-term debt financing and to minimize the cost of servicing the needed capital. There has been movement at the CAISO in this regard under a concept of energy storage as a transmission asset, but has yet to result in a long-term procurement strategy. [65]

The staff at the CPUC Energy Division have also recognized the challenge of creating incentives for long-term energy storage.[66] In a 2013 report, the CPUC staff noted that the value of a large-scale energy storage system (like pumped energy storage) is rooted in the fact that it operates as an independent asset, similar to a power generator (but not necessarily located at a generation facility), and is controlled independently of other generation sources. It adds value to the energy markets by providing and using energy and offering ancillary services. At present, however, the markets don't create adequate long-term signals to offer this value. For example, the present determination of resource adequacy (RA) is based on short-term needs. Among the possible fixes explored by the CPUC staff include a large-

scale storage Net Qualifying Capacity (NQC) value for energy storage that would offer more appropriate RA valuation, along with multi-year contracting in RA. Also useful, according to the CPUC, would be a project-specific scoring system for evaluating the full range value offered by large-scale energy storage. The CPUC has further elaborated on the benefits of large-scale storage with a "Use Case Analysis" for large-scale storage that explores in more detail how various policy reforms could unlock this value.[67]

## What is Needed?

The central purpose of this paper is to articulate the opportunities and challenges for large-scale energy storage in the evolving California grid. In particular, this paper examines the need for a decisive push to deploy pumped energy storage. The lead times for such projects are long. Having projects operationally starting in the mid 2020s requires clearer policy and market signals today. A detailed playbook for making investment in pumped energy storage happen is beyond the scope of this paper, but the elements of a California strategy would include:

- **Jump-starting a new wave of investment.** At present, while pumped energy storage is a proven technology globally, the specific arrangements for encouraging pumped energy storage investments in California are still uneven. Jump-starting investment in this area will require incentives for investment in projects along with parallel efforts to remove bottlenecks in the regulatory and policy environment, even as these projects are evaluated through all the normal environmental assessments that accompany any such large infrastructure investment. Specific incentives can encourage rapid and early investment in a few pumped storage projects that can help demonstrate business models and strategies that will make it easier to attract a larger number of projects in the future. This effort aimed at catalyzing private-sector investment and public-private partnerships could take many forms. Policymakers should begin to consider state policies that would provide reliable signals to investors to procure a suite of pumped storage projects in tandem with the most rapid buildout of renewables on the grid during the 2020s. A fresh mandate for CAISO to back procurement of such projects, or new storage mandates implemented by CPUC are examples of such policies. While the exact form of policy may vary, what is clear is that at least a few new projects must break ground soon, be constructed and enter commercial operation by the mid- to late-2020s when the need for large-scale energy storage will become critical. The incentives offered to help jump start this market should be designed so that the major beneficiaries of new pumped energy storage projects are also those who pay for the costs. This principal is standard in public sector accounting and must be applied here so that new projects are built to make them financially and politically scalable.
- **Studying the future.** While it is clear that jump-starting projects in pumped storage will be highly valuable, California would benefit from a much more aggressive program to study how the grid must evolve with the rapid shift to renewables. Elements of such a study program are already in place at CAISO, CPUC, CEC, and some think tanks, but a much more sustained and systematic look at the future is needed. A particularly urgent need is an updated approach to the IRP to address the concerns noted above, including the need to examine the consequences of a rapid shift to renewables, retirement of fossil fuel generators, and lower emissions over a much longer time horizon. This approach should look more closely at the lead times for large-scale projects, such as pumped energy storage, since investors need reliable signals earlier so that projects are ready when they are needed. This research should include attention to how changes in the federal policy environment may benefit investment in pumped storage in California. Policymakers should evaluate various cost recovery models and mechanisms, including transmission charges, tariff structures, direct load-serving entity contracting, federal energy rate opportunities, and other reasonable cost recovery approaches. Technical analysis should be complemented by analysis of the technical needs for the California grid and how they interact with market and business incentives. The studies will need to evaluate the impact to investors and operators of electric market assets and how they will respond and behave to market and business incentives.

- **Understanding the value of pumped energy storage and other forms of large-scale energy storage in a grid that is rapidly evolving in unpredictable ways.** The effort to study the future must pay very close attention to how the California grid will evolve under "real world" conditions where some of the many ways that are imagined to help integrate massive amounts of renewables don't come to fruition on the imagined schedule. Regional integration of the grid, massive optimal charging of electric vehicles, other forms of "demand response" and advanced new power electronics could all help with integration of renewables. But the scale of the effort needed and the challenges of making those options work in reality must be understood along with the risks of these options faltering. In this light, early investment in large-scale energy storage should be seen and evaluated financially and technically as central to a strategy of ensuring that California can shift to renewables and cut emissions as promised.

**Not only is pumped energy storage a proven technology that is used around the world, it also provides many additional advantages with very low risk.**

- **Identifying early projects.** As noted above, specific incentives are needed to jump-start investment in this area so that a few projects are constructed. The business models that emerge from this fresh investment in new projects will lead to a set of playbooks for how to develop and implement pumped storage projects in California. In time, normal market forces can create the right incentives for fully private sector projects to emerge, but that future won't happen automatically without some earlier projects to demonstrate how private sector participants can manage market and other risks. Some attention is needed to the attributes of the best projects to help make this jump-starting happen. Those are likely to be projects that: a) have low environmental footprints, such as projects that can utilize existing lower reservoirs; b) are close to renewable generation, transmission, and load so they can reduce or offset the need for additional investment in transmission; and c) have the involvement of public agencies that can help steward the necessary relationships between private investors and local interest groups, including land owners, environmentalists, Native American groups, and labor groups so that the projects contribute to responsible, inclusive growth.

With incentives, practical experience, and real projects moving ahead in the 2020s, the private market will follow along and build more projects as needed. That practical experience can also guide additional reforms in policy that will be needed as the California grid continues to move toward increased renewables.

## Conclusion

As a world leader in energy solutions, California is faced with an opportunity to make the shift to renewables at a cost that is acceptable to Californians. Legislative mandates are pushing that shift quickly, and failure to invest in the needed infrastructure to keep the grid reliable will undermine the economic potential and political support vital to California's grid.

While the state has begun the implementation of energy storage at a relatively small scale, the critical need for large-scale storage with long duration deployment is outpacing actual energy storage procurement. The state is relying heavily on other options such as demand response, grid integration, and flexible charging for electric vehicles, which are proving difficult to implement in the real world. Planning for real futures is essential.

Pumped storage is a proven technology that is used around the world, and provides certain advantages over other energy storage technologies including:

1. Long duration energy deployment
2. Spinning inertia that provides grid voltage and frequency regulation
3. Long lasting assets (more than 40 years)

4. Lower long-term costs
5. Lower risk

This storage is essential to enable California to meet its renewable energy and emissions goals in a cost-effective way, while maintaining reliability of the State's vital electric grid. Pumped storage projects are essential for inclusive growth and creating and keeping good jobs in the State. Legislative and regulatory support is needed to ensure the investments California has made in renewable and carbon-free energy actually deliver the benefits that Californians expect.

## Glossary of Terms

**Alternating Current (AC):** An electric current that reverses its direction many times a second at regular intervals. An example is a standard wall socket in a house. .

**Ancillary Services:** Services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system.

**Arbitrage:** The simultaneous buying and selling of products in a market. Applied to electricity it involves buying power at times when it is cheap, storing and reselling it when prices are higher.

**Automatic Voltage Regulator (AVR's):** Regulates the voltage output of a generator to ensure generators provide reactive support and voltage control, within generating facility capabilities, in order to protect equipment and maintain reliable operation of the interconnection.

**Batteries:** A device that converts chemical energy into electrical energy to provide a source of power and also electrical energy into chemical energy to provide energy storage.

**Battery Energy Storage Systems (BESS):** A compilation of batteries and auxiliary facilities, including air conditioning units to keep the batteries from overheating and inverters, needed to create a functioning system for energy storage using an array of batteries.

**Black Start:** The ability of a generator to start and interconnect with the electrical grid with no source of external power from the electric grid.

**California Energy Commission (CEC):** The CEC, established in 1974 by the Warren-Alquist Act, is the primary energy policy and planning agency for California.

**California Public Utilities Commission (CPUC):** The CPUC regulates services and utilities, protects consumers, safeguards the environment, and assures Californians' access to safe and reliable utility infrastructure and services. The essential services regulated include electric, natural gas, telecommunications, water, railroad, rail transit, and passenger transportation companies.

**California Independent System Operator (CAISO):** CAISO oversees the operation of California's bulk electric power system, transmission lines, and electricity market generated and transmitted by its member utilities.

**Carbon-Free Renewable Energy:** Energy from a source that does not cause emissions of carbon dioxide. With most known technologies, this means energy sources that do not use fossil fuels. This category includes wind, geothermal, hydroelectric, nuclear or solar power.

**Control Area:** The electrical system under the operational control of an Independent System Operator or a Regional Transmission Operator.

**Curtail/Curtailment:** The reduction or removal of renewable energy resources when they are not needed or they are unable to be exported.

**Direct Current (DC):** An electric current flowing in one direction only, such as a battery cell in a flashlight.

**Deep Decarbonization:** The removal of nearly all emissions of greenhouse gases from all sectors of the economy including energy, transportation, and energy efficiency.

**Demand Response:** The ability of an electric load to respond to price or reliability signals.

**Direct Load-Serving Entity Contracting:** A form of contractual electric supply that is dedicated to a specific load.

**Electrical Grid:** A system of generators, transmission and distribution infrastructure that matches and supplies generation with load.

**Electric Power Research Institute (EPRI):** EPRI is a nonprofit organization that conducts research and development related to the generation, delivery, and use of electricity to help address challenges in electricity, including reliability, efficiency, affordability, health, safety, and the environment.

**Energy Storage:** The ability to store energy either through a chemical process like a battery or through potential energy like water pumped uphill (pumped storage), compressed air, or flywheels.

**Federal Energy Regulatory Commission (FERC):** FERC is a United States government agency, established in 1977 to oversee the country's interstate transmission and pricing of a variety of energy resources, including electricity, natural gas and oil.

**Flywheels:** A method of energy storage and rotating speed control using a spinning mass.

**Frequency:** The time parameter of a periodically (cyclically) varying electric current, expressed by the ratio of the number of complete cycles of current variation to unit of time. The number of cycles per second is expressed as Hertz (Hz). In the United States the frequency of the AC electric system is 60 Hz.

**Governors:** A device designed to maintain a constant speed of an electric generator.

**Industrial Combustion:** The process where fuel is burned within an engine converting the chemical energy of the fuel into mechanical energy such as in a combustion engine to power an electric generator.

**Interconnecting Grids:** Independently operated grids that come together allowing coordination of power flows, frequency, reactive power and voltage.

**Lazard:** A financial advisory and asset management firm that engages in investment banking, asset management, and other financial services, primarily with institutional clients.

**Megawatts (MW):** A unit of power equal to one million watts

**Megawatt Hours (MWh):** A volume of power equal to one million watts over the period of one hour

**National Renewable Energy Laboratory (NREL):** The National Renewable Energy Laboratory (NREL), located in Golden, Colorado, specializes in renewable energy and energy efficiency research and development. NREL is a government-owned, contractor-operated facility, and is funded through the United States Department of Energy.

**Net Qualifying Capacity (NQC):** Means an estimate of the amount of Net Qualifying Capacity deliverability a project may receive in accordance with an interconnection agreement.

**Power System Stabilizers (PSS):** A control system applied at a generator that monitors variables such as current, voltage, and shaft speed and sends the appropriate control signals to the voltage regulator to dampen sudden changes in system frequency.

**Price Signals:** A price signal is a message sent to consumers and producers in the form of a price charged for a commodity. This is seen as indicating a signal for producers to increase supplies and/or consumers to reduce demand.

**Primary Frequency Control (PFC):** Ability to regulate short period, random variations of frequency during normal operation conditions and rapid response to an emergency.

**Pumped Energy Storage or Pumped Storage:** A type of hydroelectric energy storage that stores energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation.

**Renewable Energy:** Energy from a source that does not use depletable fuels (e.g., fossil fuels); the category includes wind, geothermal, hydroelectric or solar power.

**Resource Adequacy (RA):** Sufficient power resources available to reliably serve electricity demands across a range of reasonably foreseeable conditions.

**Superconducting Magnetic Energy Storage (SMES):** Systems that store energy in the magnetic field created by the flow of direct current in a wire coil that has been cooled to a point where resistance to the flow of electricity is eliminated. superconducting coil which has been cryogenically cooled to a temperature below its superconducting critical temperature.

**Supercapacitors:** Type of electrical device that can store a large amount of energy.

**T&D:** Transmission and Distribution. Transmission systems are typically defined as those systems that operate at a voltage of 100 kv or higher.

**Tariff Structures:** The regulated structure that defines the cost of electricity paid by consumers for consuming electric power. The tariff covers the total cost of producing and supplying electric energy plus a reasonable rate of return for the provider.

**Transmission Charges:** The cost of moving electric energy over the transmission system.

**Ultra-High Voltage:** Refers to power transmission lines operating at greater than 800,000 volts (800 kV).

**Uninterruptable Power Supply (UPS):**

**An electrical apparatus that provides emergency power to a load when the input power source fails.**

**Voltage:** Voltage is the electric potential difference between two points.

**Voltage Support:** The ability of an electric generator to adjust output voltage to raise or lower grid voltage.

# Acknowledgements


## Authors

1. David G. Victor has 35 years of experience studying how technology affects the structure of energy markets their impacts on major environmental challenges, such as global warming. He is a professor at UC San Diego where he co-directs the university-wide Deep Decarbonization Initiative and is also a strategic consultant to the City of San Diego on matters related to the San Vicente Energy Storage Facility. Over his career he has been involved in a large number of energy and technology modeling studies, including studies looking at expansion and integration of renewable and other zero-carbon energy sources into energy systems and the decentralization of modern power grids. He has been on the Board of the Electric Power Research Institute and a member of several scientific assessment teams, including the Intergovernmental Panel on Climate Change (IPCC) and recent committees at the US National Research Council studying resiliency and operations of the US power grid. His PhD is from the Massachusetts Institute of Technology.
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## Reviewers

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# Appendix

## METHODOLGY AND KEY ASSUMPTIONS USED IN THE LCOS ESTIMATES FOR BESS AND PS ALTERNATIVES

### METHODOLOGY

1. An electric industry standard Levelized Cost of Storage (LCOS) economic analysis process was used. A simplified spreadsheet model was developed.
2. The key assumptions, presented below, are representative of generic Pumped Storage Projects (PS) and Battery Energy Storage Systems (BESS) that would be operated for wholesale daily storage in a regional electrical grid.
3. Data taken from Lazard's Levelized Cost of Storage Analysis 00 Version 4.0 (Lazard) was used as model input for BESS alternatives. As a baseline, the study model was correlate with the results of Lazard's Lithium ion, wholesale market, 20-year life, 100MW/400 MWh alternative. The results correlate well with Lazard's LCOS of $204/MWh for the low capital cost range. For the high range cost, the model LCOS of $275/ MWh did not exactly match Lazard $298/ MWh LCOS but is deemed within an acceptable range.
4. For PS, the base model was a 40-year life, 500MW/4,000MWh project using input data from planned or recently evaluated pumped storage projects in California. The key assumptions were discussed with Black & Veatch along with investors and equipment suppliers and contractors to confirm they were within industry norms.
5. Once the BESS and PS baseline models were established, the following sensitivities were performed, as discussed in the report and as summarized in the table found at the end of this Appendix:
    a. The baseline 20-year life BESS project using low-range cost factors. (Column A)
    b. A 20-year life BESS project using high-range cost factors. (Column B)
    c. To provide a comparison of LCOS between PS and BESS for both high and low range costs, 40-year BESS life-extended projects were developed. (Columns C and D)
    d. The baseline 40-year PS project. (Column E)
    e. A 50-year life PS project. (Column F)
    f. To reflect the potential 100-year life of PS, an estimate of the LCOS for an additional 50-year PS life. (Column G)

### KEY ASSUMPTIONS

1. The commercial operation year was selected as 2026 and is the earliest reasonable year that a pumped storage project would be operational. Adjustment of Lazard's 2018 cost basis was considered and discussed below.
2. The modeled plant capacity (MW) is the net power supplied at the point of interconnection (POI) to the grid. To match Lazard assumptions, the plant capacity does not include the additional plant capacity required to offset power loss due to step-up transformer efficiency and transmission line to the POI. If this were to be included an additional 10%-15% would need to be added to both alternatives.

3. The energy storage (MWh) is calculated as the product of the capacity times the hours of plant operation in the generating or discharge mode.
    a. For BESS it was selected based on the Lazard report as four hours. This is acknowledged as being non-conservative as BESS has not been demonstrated that the batteries can be fully discharged. Allowable discharge duration of 2-3 hours would be more realistic and conservative. For purposes of this analysis and to compare more directly to Lazard, the full discharge depth / full capacity is assumed.
    b. For PS, in order to achieve minimum economics of scale and support daily storage operation eight hours at full generating capacity is selected. This a significant difference between the two technologies.
4. With respect to plant availability and capacity factor:
    a. Lazard, page 28, reports a BESS project would be available 350 days a year, each day operating for 4 hours at full capacity. This works out to a capacity factor of about 16%.
    b. For the pumped storage, it was assumed that there will be slightly more downtime for mechanical maintenance outages and that the plant would operate 329 days a year, each day operating for 8 hours at full capacity or a capacity factor of 30%.
    c. Depending on the actual CAISO dispatch needs, the differences in capacity factor indicate a PS could provide additional energy storage and grid support services.
5. With respect to assumed capital costs:
    a. Lazard reports cost factors that are dependent on the project utilization. Extrapolating data on pages 6 and 28 and using their wholesale market parameters, the following range of 2018$ capital cost factors were assumed:
        i. BESS Equipment Cost. Lazard, page 28, range of $232/MWh - $398/MWh of storage capacity (400MWh).
        ii. Inverter Cost. Lazard, page 28, range of $49 /MW -$61 / MW of plant capacity (100MW).
        iii. Balance of System Cost. Lazard, page 6, footnote 6, $27.00/kWh of storage capacity. This was kept constant.
        iv. EPC Cost. Lazard, page 6, applied a 16.7% mark-up to the sum of the BESS, Inverter and Balance of System Costs.
        v. BESS Cost Escalation to COD. As noted above the Lazard costs are in 2018 dollars. For purposes of this analysis, capital costs were assumed to remain constant to a 2026 COD.
    b. PS capital costs are dependent partly on the particulars of the individual sites. A project was configured to reflect the following:
        i. An existing lower reservoir.
        ii. An underground powerhouse with four x 125 MW pump turbine units.
        iii. An upper reservoir using a ring dike.
        iv. After reviewing a number of available alternative cost estimates, the Iowa Hills Pumped Storage project was judged as the most recent and a reasonable basis. It has a reported $2016 cost per MWh of $453,000/MWh. Adjusting for differences in scope and timing, a $2026 cost of $477,000 was selected.
    c. Capital costs for BESS and PS did not include land costs, development costs, or transmission cost.

6. The energy required to charge the BESS or pump-back to an upper reservoir is equal to the total annual generation divided by the applicable cycle efficiency.
    i. Lazard, page 6, calculates annual charging energy based on 140,000 MWh of annual generation and an 87% cycle efficiency.
    ii. PS pump-back energy was based on annual generation energy of 1,314 GWh. Typical cycle efficiencies range from 75%-85% depending on equipment selected and project configuration. A 77% mid-range efficiency was selected.
    b. Given California's recent history of negative pricing, curtailment of off-peak energy generation and the changing of the utility rate structures to time-of-use basis, predicting the future 2026 energy rates is challenging. Lazard used a generic US energy purchase rate of ($2018) $33 per MWh escalated at 0.55% per year. Reviewing CPUC and EIA data for 2018 indicated a range of $15 to $25 per MWh. $22/MWh was selected and escalated at 1.25% to $24/MWh ($2026) for PS pumping energy.
    c. While Lazard's BESS 2018 basis charging energy cost is slightly higher than PS pumping energy cost basis, it is escalated at a lower rate. The 20-year BESS model was sensitized using the PS basis. This would reduce the BESS LCOS by about 3%. It did not change the comparative results. It was decided to use the Lazard rates for the BESS in order to maintain compatible results with Lazard.
7. With respect to annual O&M costs:
    a. BESS was modeled using Lazard data, page 6, which indicated a year 1 cost of $5.7 million escalated at 2.5%.
    b. For PS a line item estimate was developed that resulted in a year 1 cost of $8.8 million, also escalated at 2.5%.
8. To analyze the impact to the BESS LCOS to extend the life from 20-years to 40-years, the following model adjustments were performed:
    a. Lazard acknowledges that BESS equipment performance will degrade over time and provides an O&M allowance of 4.2% of original BESS installed cost for what they call "augmentation". This is understood to be an addition of BESS modules to make up for degraded storage over time. This however does not reflect the cost to extend the life of the full project for another 20 years.
    b. Starting in year 15 the BESS equipment will be modernized and upgraded to industry standards in place at that time. Since actual scope and cost for life extension is unknown, it was assumed as follows:
        i. The life-extension cost would be 75% of the Lazard BESS equipment module cost of $205/MWh (page 6, footnote 4) or $154/MWh.
        ii. All other costs would have been covered by the Lazard augmentation cost included in their base O&M cost.
        iii. The life-extension would occur over a five-year period.
        iv. To provide funding a reserve account would be set-up and funded using an additional O&M cost of $2.75 Million per year (constant). The reserve fund would earn interest at 5%.
9. To analyze the impact to the PS LCOS to extend the life from 50-years to 100-years, the following model adjustments were performed:

a. A separate 50-year LCOS analysis was performed to reflect a significantly different cost structure since debt and equity return will be drastically reduced.
b. A new debt of $360 million was added and amortized for 50 years to pay for refurbishing the pump-turbines, and other project features.
c. The Year 1 pumping and O&M costs were carried over from the original 50-year analysis. Both were escalated at 1.25% from that point.
d. The LCOS for this analysis used a starting year of 2076. For presentation purposes the 2076 LCOS value was brought back to a 2026 starting year using a deflation rate of 1.25%.

10. Financial model parameters are significantly different for BESS and PS projects due to their historic financial performance and project specific risk profiles. The following parameters were used:
    a. The internal rate of return (IRR) for each alternative was set constant at 12% and is equal to what was used in the Lazard report (Version 4.0).
    b. Debt / Equity Ratio
        i. Lazard uses 20% debt / 80% equity (page 6). This was adopted for this study.
        ii. Pumped storage was evaluated at 66% debt / 34% equity.
    c. Financing Terms. Both BESS and PS assume financing by private developers.
        i. Lazard assumed an 8%, 20-year debt service (page 6). No further back-up data is available on this rate selection but is assumed for this study based on Lazard's knowledge of the BESS industry.
        ii. Based on discussions with pumped storage developers, an interest rate range of 5% to 6% for a 40-year debt service. A separate calculation arrived at a rate of 5.52% based on recent 30-year forward Treasury rate of 3.27% plus a 2.25% spread was used.
    d. Taxes. Both BESS and PS assume a combined federal and state income tax rate of 28% on net taxable income. Lazard did not include a cost allowance for property taxes so both models do not include property taxes.

Levelized Cost of Storage Analysis
Summary Tables

| CRITERIA | UNIT | BESS --20 YR (LOW) | BESS --20 YR (HIGH) | BESS --40 YR (LOW) | BESS --40 YR (HIGH) |
|---|---|---|---|---|---|
| | | A | B | C | D |
| **Financial Results** | | | | | |
| Developer IRR | | 12% | 12% | 12% | 12% |
| LCOS | $/MWh | $ 204.00 | $ 275.00 | $ 218.00 | $ 285.00 |
| Levelizing Starting Year | | 2026 | 2026 | 2026 | 2026 |
| | | | | | |
| **Investment** | | | | | |
| Project Capacity at POI (MW) | | 100 | 100 | 100 | 100 |
| Storage (MWh) per day | MWh | 400 | 400 | 400 | 400 |
| BESS Initial Unit Cost | $/MWh | $ 232.00 | $ 398.00 | $ 232.00 | $ 398.00 |
| BESS Initial Cost | x1000 | $ 92,800 | $ 159,200 | $ 92,800 | $ 159,200 |
| Inverter Unit Cost | $/kW | $ 49.00 | $ 61.00 | $ 49.00 | $ 61.00 |
| Inverter Cost | x1000 | $ 4,900 | $ 6,100 | $ 4,900 | $ 6,100 |
| BOP System Unit Cost | $kwh | $ 27.00 | $ 27.00 | $ 27.00 | $ 27.00 |
| BOP System Cost | x1000 | $ 10,800 | $ 10,800 | $ 10,800 | $ 10,800 |
| Subtotal | x1000 | $ 108,500 | $ 176,100 | $ 108,500 | $ 176,100 |
| EPC Mark-up | 16.7% | $ 18,120 | $ 18,120 | $ 18,120 | $ 18,120 |
| Total Capital Cost | x1000 | $ 126,620 | $ 194,220 | $ 126,620 | $ 194,220 |
| | | | | | |
| **Operating Parameters** | | | | | |
| Operating Days per year | | 350 | 350 | 350 | 350 |
| Generating Hours Per Day | | 4 | 4 | 4 | 4 |
| Annual Generation | MWh | 140,000 | 140,000 | 140,000 | 140,000 |
| | | | | | |
| **Charging Cost** | | | | | |
| Annual Generation | MWh | 140,000 | 140,000 | 140,000 | 140,000 |
| Daily Storage Hours | Hours | 4 | 4 | 4 | 4 |
| Cycle Efficiency | | 87% | 87% | 87% | 87% |
| Pumping Energy | MWh | 160,920 | 160,920 | 160,920 | 160,920 |
| Charging Rate | | $ 0.033 | $ 0.033 | $ 0.033 | $ 0.033 |
| Year 1 Charging Cost | x1000 | $ 5,310 | $ 5,310 | $ 5,310 | $ 5,310 |
| Charging Rate Escalator | | 0.55% | 0.55% | 0.55% | 0.55% |
| | | | | | |
| O&M Cost | | | | | |
| Year 1 O&M Cost | x1000 | $ 5,700 | $ 5,700 | $ 5,700 | $ 5,700 |
| O&M Escalator | | 2.50% | 2.50% | 2.50% | 2.50% |
| | | | | | |
| **Financial Inputs** | | | | | |
| Tax rate on net income | | 28% | 28% | 28% | 28% |
| Interest rate on loan | | 8% | 8% | 8% | 8% |
| Time period for loan (years) | | 20 | 20 | 20 | 20 |
| Reserve Account Contribution | | 0 | 0 | $ 2,575 | $ 2,575 |
| Debt | 20% | $ 25,324 | $ 38,844 | $ 25,324 | $ 38,844 |
| Equity | 80% | $ 101,296 | $ 155,376 | $ 101,296 | $ 155,376 |
| Reserve Interest | | NA | NA | 5% | 5% |

Levelized Cost of Storage Analysis
Summary Tables

| CRITERIA | UNIT | PS -- 40 YR | PS--50 YR | PS--YR 51-100* |
|---|---|---|---|---|
| | | E | F | G |
| **Financial Results** | | | | |
| Developer IRR | | 12% | 12% | 12% |
| LCOS | $/MWh | $ 186.00 | $ 177.00 | $ 108.00 |
| Levelizing Starting Year | | 2026 | 2026 | 2076 |
| | | | | |
| **Investment** | | | | |
| Project Capacity at POI (MW) | | 500 | 500 | 500 |
| Storage (MWh) per day | MWh | 4,000 | 4,000 | 4,000 |
| Unit Capital Cost | $/MWh | $ 477 | $ 477 | $ 90 |
| Capital Cost | x1000 | $ 1,906,000 | $ 1,906,000 | $ 360,000 |
| Subtotal | x1000 | $ 1,906,000 | $ 1,906,000 | $ 360,000 |
| Total Capital Cost | x1000 | $ 1,906,000 | $ 1,906,000 | $ 360,000 |
| | | | | |
| * Levelized cost using a start date of 2026 is $58.00 using a 1.0125% de-escalator. | | | | |
| | | | | |
| | | | | |
| | | | | |
| | | | | |
| **Operating Parameters** | | | | |
| Operating Days per year | | 329 | 329 | 329 |
| Generating Hours Per Day | | 8 | 8 | 8 |
| Annual Generation | MWh | 1,314,000 | 1,314,000 | 1,314,000 |
| | | | | |
| **Charging Cost** | | | | |
| Annual Generation | MWh | 1,314,000 | 1,314,000 | 1,314,000 |
| Daily Storage Hours | Hours | 4 | 4 | 4 |
| Cycle Efficiency | | 77% | 77% | 77% |
| Pumping Energy | MWh | 1,706,494 | 1,706,494 | 1,706,494 |
| Charging Rate | | $ 0.024 | $ 0.024 | $ 0.024 |
| Year 1 Charging Cost | x1000 | $ 40,956 | $ 40,956 | $ 75,279 |
| Charging Escalation | | 1.25% | 1.25% | 1.25% |
| | | | | |
| O&M Cost | | | | |
| Year 1 O&M Cost | x1000 | $ 8,781 | $ 8,781 | $ 23,000 |
| O&M Escalator | | 2.50% | 2.50% | 2.5 |
| | | | | |
| **Financial Inputs** | | | | |
| Tax rate on net income | | 28.00% | 28.00% | 28.00% |
| Interest rate on loan | | 5.52% | 5.52% | 5.52% |
| Time period for loan (years) | | 40 | 50 | 50 |
| Reserve Account Contribution | x1000 | $ 1,888 | $ 1,888 | $ 1,888 |
| Debt x1000 | 66% | $1,255,482 | $1,255,482 | $ 216,000 |
| Equity x1000 | 34% | $ 650,518 | $ 650,518 | $ 144,000 |
| Reserve Interest | | 5% | 5% | 5% |

The CHAIRMAN. Thank you, Mr. Davidson.
Mr. Fowke.

**STATEMENT OF BEN FOWKE, CHAIRMAN, PRESIDENT, AND CHIEF EXECUTIVE OFFICER, XCEL ENERGY INC.**

Mr. FOWKE. Chairman Murkowski, Ranking Member Manchin and distinguished members of the Committee, my name is Ben Fowke and I'm Chairman, President and CEO of Xcel Energy. I really appreciate the opportunity to provide Xcel Energy's perspective on grid-scale storage and its great potential for the utility industry.

Xcel Energy is a public utility holding company serving 3.6 million electric customers and 2 million natural gas customers. Headquartered in Minneapolis, we serve parts of eight Western and Midwestern states including Minnesota, Colorado, North and South Dakota, Wisconsin, Michigan, Texas and New Mexico.

Xcel Energy is leading the way to a clean energy future by transitioning away from coal to renewables and other cleaner technologies, all while keeping electricity rates affordable and our system reliable. We already have achieved a 38 percent system-wide reduction in carbon dioxide emissions from 2005 levels and we're aiming to go much higher.

Xcel Energy is the first utility in the country to announce the goal of providing carbon-free electricity by 2050 with a near-term target of reducing carbon emissions by 80 percent by 2030. This vision is ambitious and its success depends of the development of new technologies that will continue to ensure a reliable, affordable grid.

Those new technologies will undoubtedly include energy storage. We have been increasing our understanding of storage and how it works on our system, particularly pumped hydro and batteries. For 50 years we've operated a 324-megawatt pumped-storage facility in Colorado. We have also learned more about the value of battery storage through innovative pilot projects in Minnesota and Colorado. I'm excited about the possibilities of grid-scale storage technologies and the potential services and value they can offer our customers. While we're in the early days of energy storage and many challenges remain, I believe storage has the potential to play an important role in the electric grid of the future.

Wind and solar provide low-priced, clean energy to our customers but they are intermittent and seasonal. Grid-scale storage can help with renewable integration allowing higher renewable energy penetration levels than would otherwise be possible.

Storage can also provide other importance to the grid and customers, including more reliable grid operations, voltage support, frequency control. Already batteries are being used to provide backup power to customers with specific power quality needs. Electric utilities are currently taking advantage of many different values of grid-scale storage. In fact, utilities are the leading developers of storage technologies in the nation.

In Colorado, for example, we're calling for up to 275 megawatts of storage capacity in our Colorado energy plant. The storage capacity proposal is one of the largest of its kind in the country. I'm

excited by the potential value of storage, especially as the technology advances and the prices decline.

While the possibilities of storage technology are certainly promising, many people have misconceptions that batteries can address all future challenges of a clean energy grid. In fact, batteries and other storage technologies still have limitations and like all things in energy, there is no silver bullet.

First, storage today cannot solve the problem of wide seasonal variation in renewable energy generation which is the chief factor preventing the creation of a fully renewable electricity system. Today's best battery storage systems provide a few hours of storage for a few megawatt-hours of energy. However, for a fully renewable grid, we would need to store huge amounts of energy for months at a time. The cost of seasonal storage today is prohibitive.

Second, while storage can initially help integrate renewables by moving energy from the time it is produced to the time it is needed, the value of each increment of storage capacity declines as more storage is added to the system. Eventually new storage has little additional value in helping integrate renewables.

And finally, although storage can bring multiple services to the grid—power quality and grid support, for example—we usually cannot add the value of all of these services together. As a general rule, they're not all available at the same time.

The right public policies can help address these challenges. The Federal Government is uniquely positioned to promote further energy storage research, development and deployment as part of a larger clean technology program. Incentives are also important, but they need to be the right design to be effective. My written testimony sets forth these and other policies we think would support the bright future we see in grid-scale storage.

In closing, I'm optimistic about the future for storage technology and believe it will be an important part of the mix as we work toward our vision of a clean energy future that is both reliable and affordable.

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

[The prepared statement of Mr. Fowke follows:]

**STATEMENT OF**

**BEN FOWKE**

**CHAIRMAN, PRESIDENT, AND CHIEF EXECUTIVE OFFICER**

**XCEL ENERGY INC.**

**BEFORE THE**

**U.S. SENATE COMMITTEE ON ENERGY AND NATURAL RESOURCES**

**HEARING ON**

**EXPANDED DEPLOYMENT**

**OF GRID-SCALE ENERGY STORAGE**

**JUNE 4, 2019**

**1. Introduction**

Chairman Murkowski, Ranking Member Manchin, and distinguished members of the Committee, thank you for inviting me to testify before you today.

My name is Ben Fowke, and I am Chairman, President and CEO of Xcel Energy, a public utility holding company serving 3.6 million electricity customers and 2 million natural gas customers through four utility subsidiaries. Headquartered in Minneapolis, we serve parts of eight Western and Midwestern states, including Minnesota, Colorado, North Dakota, South Dakota, Wisconsin, the Upper Peninsula of Michigan, the Texas Panhandle and Southeastern New Mexico.

At Xcel Energy, we have already achieved a 38% system-wide reduction in carbon dioxide emissions from 2005 levels, but we aim to go much further. Our experience shows us that, with the right strategy, we can achieve remarkable levels of emission reductions while simultaneously preserving the reliability and affordability of our electric system. A few months ago, I was proud to announce Xcel Energy's industry-leading carbon emission reduction strategy. Under that strategy, we have set in motion a plan to achieve an 80% reduction in carbon emissions by 2030, and a vision to be completely carbon-free by midcentury.

Technology is the key to the success of our strategy. The emission reductions that we have achieved to date have relied heavily on the deployment of affordable renewable energy technologies, especially one of the nation's leading wind energy portfolios. We will continue to add new renewable energy to our system as long as it makes sense, but at some point we will need new, clean energy technologies if we are to maintain an affordable, reliable energy system.

Those new technologies will undoubtedly include energy storage. For this reason, I want to thank the members of this Committee for holding today's hearing. I am excited about the

possibilities of grid-scale storage technologies and the potential value it can offer to our utility system and customers as we continue to reduce our carbon dioxide emissions. While we are in the early days of energy storage and many challenges remain, I believe storage has the potential to play an important role in a carbon-free electric grid.

**2. Overview: Storage has a bright future.**

As I have already stated, Xcel Energy's long-term carbon strategy depends on the deployment of advanced clean technologies. One of the most important of those technologies is grid-scale energy storage. Today, storage is beginning to play a more important role in our electric system, and we see it as a valuable part of the future of electricity service.

My testimony describes how storage can help utilities manage growing renewable energy portfolios. Wind and solar provide low-priced, clean energy to customers, but they are "intermittent": they generate when the wind blows or the sun shines, not necessarily when our customers need it. Despite their many benefits, high levels of renewables represent an operational, reliability and, eventually, cost challenge for our system.

That's where storage comes in. As discussed in more detail below, grid-scale storage helps with renewable integration, allowing higher renewable energy levels than would otherwise be possible. Storage can also provide other system benefits, including more reliable grid operations, voltage support and frequency control.

The good news is that utilities are already taking advantage of the many different values of grid-scale storage. In fact, utilities are the leading developers of storage technology in the nation. That makes sense: storage is first and foremost a grid asset, and, as grid owners and operators, utilities are uniquely situated to maximize the multiple benefits of storage. As I detail

in this testimony, Xcel Energy has a number of advanced storage projects already deployed on our system and a growing interest in using storage in the future.

At the same time, we also recognize that storage today still has limitations. My testimony discusses two significant challenges for storage: First, storage cannot today solve the problem of the wide seasonal variation in renewable energy generation, which is the chief factor preventing the creation of fully renewable electricity system. Second, while storage can initially help integrate renewables by moving energy from the time it is produced to when it is needed, the value of each additional increment of storage capacity declines as more is added to the system. Finally, although storage can bring multiple services to the grid – power quality and grid support, for example – the value of all of these services are not all additive (or "stackable"). As a general rule, these services are not all available at the same time.

Despite these challenges, I am bullish on the potential of storage as a part of our electricity system. Good policies are critical to enabling the optimal deployment of storage, and federal support is especially important. Federal policies should promote storage research, development and deployment as part of a larger clean technology program. Incentives are also important, but they need the right design to be effective. My testimony sets forth these and other policies we think would support the bright future we see for grid-scale storage.

**3. Xcel Energy has broad and growing experience with storage.**

Electricity storage devices include a variety of technologies that store electrical energy directly (e.g. capacitors) or, more typically, after converting to some other form of potential or kinetic energy. For example, pumped hydro storage facilities use electrical energy to pump water to a higher elevation and store that water as gravitational potential energy; flywheels use

electrical energy to rotate a mass to high velocities and thus store energy as kinetic energy; compressed air projects store energy in a geologic formation as pressurized potential energy; and batteries use electrical energy to drive chemical reactions and then store that energy as chemical potential energy. As no energy conversion process occurs without inefficiencies or losses, any energy storage system will discharge a lesser amount of energy than used to charge the device. If deployed properly, energy storage can help enable a smarter, stronger, cleaner and more reliable grid.

Xcel Energy has long been a leader in deploying energy storage. We have operated pumped storage hydro energy storage on our system for decades and have adapted its operation to meet our evolving system. Today, we are implementing pilots and other programs exploring new storage technologies that will play a role in our energy future.

***Cabin Creek Pumped Storage***. Historically pumped storage hydro has been the dominant source of energy storage – even today, nearly 92% of operational storage in the US is pumped storage. Our largest energy storage asset is the 324 MW Cabin Creek pumped hydroelectric storage facility in Colorado. The Cabin Creek facility was built in 1967. Like all pumped storage facilities, it has an upper and a lower reservoir. When economic, we pump water from the lower to the upper reservoir. When the system has additional energy needs, we allow the water to "spill" out of the upper reservoir to the lower through a hydro turbine to generate electricity. Originally, the facility was used to transfer excess energy from off-peak hours to on-peak hours, but today it is also used for renewable energy integration. We spill water to meet customer demand when the wind stops blowing and pump water to the upper reservoir during times when the wind energy generated on our system exceeds customer demands.

***Luverne MinnWind Storage Project:*** The Luverne wind-to-battery project in Minnesota was one of the first battery storage pilot projects our company pursued and the first U.S.-based pairing of wind energy and a storage battery. The pilot was intended to test the various ways batteries could be used to provide wind integration and regulation services supporting the energy grid. The 1 MW, 7 MWh sodium sulfur battery paired with an 11 MW wind project has been in-service since 2009, and was recently updated by the manufacturer with new grounding technology and cells, extending the life of the battery and allowing us to test new battery applications. It was funded in part by a $1 million grant from Minnesota's Renewable Development Fund.[1]

***SolarTAC*:** We are the original founding member, host utility and a development partner at the Solar Technology Acceleration Center (SolarTAC), an outdoor solar testing facility located in Aurora, Colorado.[2] Together, the solar industry and utilities work at SolarTAC to test, validate and demonstrate advanced solar technologies under actual field conditions. We worked with our SolarTAC partners to test two different battery storage projects.

- A community energy storage project at SolarTAC is testing a more cost-effective way to improve the integration of solar power in areas with high solar production. Working with the Electric Power Research Institute (EPRI), we are testing a 25-kilowatt battery integrated with four small photovoltaic installations that simulate a neighborhood with multiple rooftop solar power systems.

[1] Xcel Energy Wind-to-Battery Project: https://www.xcelenergy.com/staticfiles/xe/Corporate/Environment/wind-to-battery%20fact%20sheet.pdf
[2] Solar Technology Acceleration Center: http://www.solartac.org/

- Through our Solar2Battery project, we installed a 1.5 MW battery to evaluate how energy storage can help in operating the electricity grid with energy from large-scale solar facilities.

These projects have increased our knowledge of how batteries respond to intermittent solar generation, how battery chemistries perform over time, and how energy storage systems can create value for our system.

***Innovative Clean Technologies Program*:** The Colorado Public Utilities Commission has approved an Innovative Clean Technologies (ICT) program to test emerging technologies that are designed to lower carbon emissions associated with electricity service. We currently have two battery storage demonstration projects operating under the ICT program:

- Stapleton Community Energy Storage Project: As demand for solar energy at our customers' homes and businesses increases, we are examining how battery storage can help integrate higher concentrations of customer solar energy on our system. Through a project in Denver's Stapleton neighborhood, Xcel Energy installed six customer batteries and six larger grid batteries to test rooftop solar integration and grid support capabilities.[3]
- Panasonic Battery Demonstration Project: Through a public-private partnership, Xcel Energy, Panasonic and Denver International Airport are collaborating to test a battery storage system that can both serve as a microgrid to provide backup power to Panasonic's Denver headquarters and support Xcel Energy's grid at other times. As part of the project, Xcel Energy owns a 1.3 MW solar carport installation and a 1

[3] Community Storage Project in Stapleton Neighborhood: https://www.xcelenergy.com/energy_portfolio/innovation/stapleton

MW/2MWh lithium ion battery. Panasonic also owns a 0.20 MW solar array located atop its building, which is also tied into the system.[4]

These pilot projects have provided great operational experience for future, widespread deployment of batteries on our system. From these projects, we have gained detailed information on the value, costs and benefits of battery installations. The projects demonstrate the need for better interoperability between the devices and systems. They will inform future system architecture, including cybersecurity and interconnection issues associated with battery operation. In addition, we currently have nearly 300 residential batteries installed across our states and are working with customers and the storage industry to provide battery interconnection guidelines and support.

***Colorado Energy Plan:*** The Colorado Energy Plan (CEP) is the next step in our efforts to transform our energy system for our Colorado affiliate. It includes the retirement of two existing coal units and the construction of 1,100 MW of new wind and 700 MW of new solar. As part of the all-source bids associated with the CEP, we received 133 total energy storage bids from 97 separate projects. Taking advantage of the tax credit incentives, several of the project developers were able to present us with very competitive pricing for batteries paired with solar. From these bids, we selected two separate battery-plus-solar projects totaling over 600 MW of universal scale solar paired with 275 MW of battery storage, which was then the largest utility-proposed acquisitions of battery storage in the U.S. The Colorado Public Utilities Commission approved CEP in August 2018, and with this approval we are moving forward to implementation.

[4] Panasonic Battery Demonstration Project: https://www.xcelenergy.com/staticfiles/xe-responsive/Energy%20Portfolio/CO-Panasonic-Fact-Sheet.pdf

As I'll discuss below, it's important to understand that storage has both benefits and challenges. However, the CEP bids showed the nation that storage has arrived as a grid resource.

**4. Energy storage has multiple values to an electricity system**

Energy storage can be deployed in all parts of the energy grid, and can help to enable a smarter, stronger, cleaner, and more reliable energy grid for all customers. Although there are multiple opportunities for energy storage to add value to our system, today I will focus on four key areas: renewable integration, grid support, deferred investment, and power quality.

***Renewable Energy Integration:*** As Xcel Energy continues to add significant amounts of renewable energy generation to our system, energy storage can support integrating those renewables into the energy grid. Renewable energy is available when the wind blows or the sun shines, and customer energy demand is often not synchronized with its availability. Storage can help shift renewable energy to time periods when it is needed, reducing the need for investment in peaking plants and support facilities. This is especially true for short-term deviations – a few minutes to a few hours – between customer demand and renewable generation. The Colorado Energy Plan, referenced earlier, demonstrates that storage can play an important role in the near-term to cost-effectively incorporate renewables on the system.

***Grid Support:*** As the owners and operators of the grid, utilities are first and foremost responsible for the safety, reliability, and optimal operation of our system for our customers. A reliable electric system requires attention to the physics of electricity transmission and distribution. It is not enough to match generation and power supply; we also must make sure that the power can be delivered to customers. Energy storage can help with grid reliability and resilience by providing:

- voltage support at critical places on the electric system where low voltage prevents the transmission of power;
- frequency regulation, ensuring that the appropriate frequency of the alternating current on the system is maintained;
- readily available reserves, reducing the need for additional investments in "quick start" generation and transmission assets that maintain the system in the event of a disruption; and
- Black start capability, or the ability to restart the entire electric system in the event the whole system goes down.

Utilities are well-positioned to maximize the value of these storage capabilities to ensure system planning and visibility with the primary objective of enhancing reliability and optimizing performance in a cost-effective manner. We can facilitate the deployment of energy storage on our system when and where it is most needed.

***Deferred Investment:*** Storage has the potential to take the place of traditional grid investments across our system, including fulfilling the role of new peaking generation, transmission and distribution upgrades, and reliability investments to maintain grid support. Its ability to do so depends on whether the proposed storage resource is (1) capable of providing the same benefits as the asset it replaces; and (2) cheaper than the more traditional alternative. Increasingly, the price of storage combined with solar (with the federal investment tax credit) is on par with the price of a gas-fired peaking facility. As storage technologies continue to improve and prices come down, there are greater opportunities for storage to take the place of existing technologies, especially in areas where the unique circumstances of the system make traditional technologies more expensive.

We are actively exploring additional deferral opportunities for our system where storage may provide a solution. This requires new tools and processes to analyze the appropriate location and size of the potential storage solution, as well as a cost-benefit analysis of those solutions as compared to traditional grid investments. Properly positioned storage can defer or reduce the need for incremental transmission and distribution investments, while poorly-sited storage may require additional investments in new capacity or distribution upgrades.

***Power quality:*** Given society's growing dependence on electronic devices, some customers seek power quality above and beyond what is provided by our standard electric service. Batteries can improve power quality by helping avoid the momentary outages that interfere with the operation of sensitive electronic equipment. Projects like our Panasonic pilot have demonstrated the value of customer-utility partnerships in addressing these issues by placing a utility-owned battery close to, or at, a customer site to provide premium power quality service, while also allowing the utility to leverage the battery for grid services.

I am optimistic about these and other benefits of grid-scale storage. Key to capturing the full spectrum of these benefits is the recognition that storage is first and foremost a grid asset. As more and more energy storage is deployed on our system and across the country, it is important that the rules governing ownership and operation of energy storage assets are clear and aimed at maximizing the grid benefits of storage while encouraging its affordable, reliable and safe deployment. Utilities are uniquely situated to understand the grid and its needs and should play an important role both in owning and operating grid-scale storage.

**5. Despite its potential, storage today cannot address all of the challenges associated with the development of a carbon-free electric system.**

Energy storage offers companies like Xcel Energy great opportunities to provide better, more efficient energy service. It will enhance our operations, help us integrate renewable energy, and play an important role in achieving our clean energy vision. At the same time, storage is not a silver bullet that would solve all electricity system challenges. While we see storage as a growing part of our energy system, it must be part of a diverse clean energy portfolio. Storage has inherent limitations that policy makers and utilities must keep in mind as we invest in the energy system of the future.

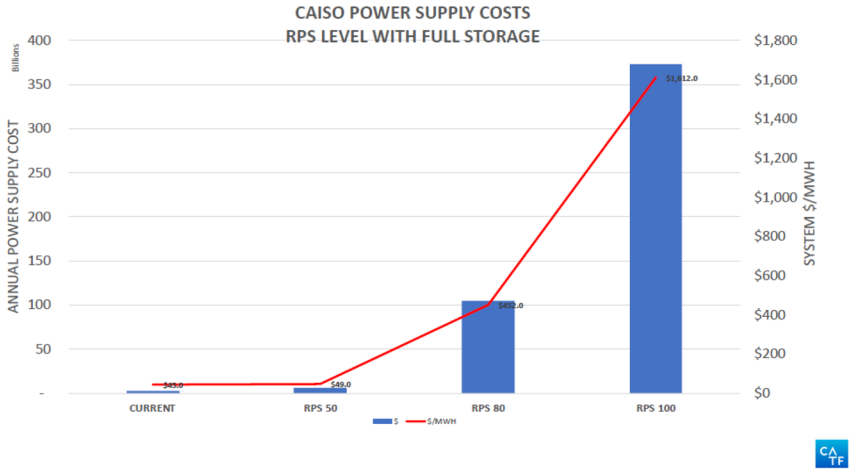
*Seasonal renewable variation.* No company is more committed to renewable energy than Xcel Energy, and no company has done more to integrate growing levels of renewables. Wind and solar have been a key part of our strategy for more than a decade, and we plan to continue to add renewable energy as long as we can do so cost effectively and reliably.

By 2030, however, we anticipate that we will be close to what today appears to be the economic and operational limits of renewable penetration. As I discussed above, storage has growing value to help integrate renewable energy on the electric system. However, it will not enable the transition to an all-renewable electric system.[5] The problem of seasonable variation on a 100% renewable energy grid is a problem that grid-scale energy storage cannot solve today.

Wind and solar resources are not consistently available and controllable to serve the energy needs of all customers all the time on the whole energy system. For our system today, the cost of integrating renewable energy is manageable up to about 50 to 60% renewable penetration. At that point, however, the cost of integrating additional renewable energy begins to climb rapidly. The following chart, derived from a Clean Air Task Force (CATF) analysis of the

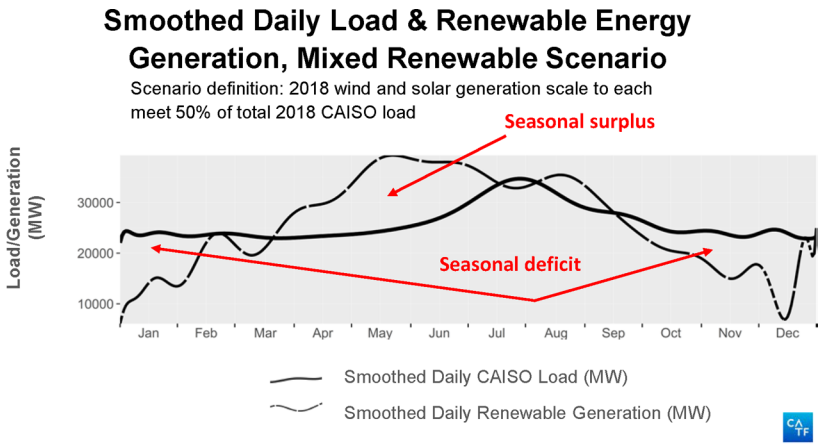
[5] Today, it is possible for individual customers to use financial transactions and customer products to match 100% of their energy consumption with renewable sources; Xcel Energy provides customers with the opportunity to enhance their renewable energy leadership through products like Renewable*Connect. However, the success of these products does not mean that the entire energy system can accommodate 100% renewable energy.

California energy system, shows the impact of increasing levels of renewable penetration.[6] As this chart demonstrates, at levels of renewable penetration above 70%, the cost of adding the next MW-Hr of renewable energy becomes untenable.[7]




Seasonal variation in renewable generation is the primary reason that the cost of renewable energy grows so substantially as renewable penetration increases. The CATF chart below shows that, during the periods when renewable output is very high, the California energy system would generate substantial additional renewable energy. This additional renewable energy would have to charge a massive amount of battery capacity to ensure that load is served when renewable output is relatively low.

[6] Clean Air Task Force analysis of CAISO data. February 2019.
[7] *$2.5 trillion reason we can't rely on batteries to clean up the grid,* James Template, August 4, 2018. https://www.wind-watch.org/documents/the-2-5-trillion-reason-we-cant-rely-on-batteries-to-clean-up-the-grid/




In fact, CATF estimates that 9.6 million MW-hours of energy storage would be required to achieve 80% renewables in California—compared to the roughly 150,000 MW-hours of storage in California now. To reach 100% renewables, CATF has concluded that California would need 36 million MW-hours of storage.

The cost of storage to achieve 100% in California would be astronomical – at 100% renewables, $3.6 trillion in capital costs to store all the surplus renewable generation, even assuming a 60% drop from today's storage costs. CATF's analysis applies equally well outside of California. Based on external analysis of our carbon reduction plans for our Upper Midwest system, achieving even an 80% reduction in $CO_2$ emissions is more than twice as expensive if we exclude new firm resources (including natural gas) and attempt to reach this goal with only renewable energy plus storage.[8]

[8] Energy and Environmental Economics analysis of Xcel Energy's Upper Midwest portfolio, April 17, 2019.

We remain committed to providing our customers with a carbon-free electric system, and we will add renewable energy to that system as long as it makes sense. In my testimony, I have been clear that storage will play an important role in a future clean energy system. However, given the huge challenge of seasonal variation in renewable generation, it is not realistic to expect that storage will make a 100% renewable energy system possible. Storage alone cannot provide the American people with the reliable and affordable energy that they need. A broader suite of new dispatchable zero carbon technologies will be key to achieving our long-term carbon goals.

*Peak demand shifting.* Storage can help meet peak energy demand by shifting some excess renewable energy to periods when it is needed. This is a great benefit, but its value declines dramatically as more storage is added to the system.

As its name implies, a system peak is like the top of a mountain or a pyramid. It represents a short period of time during each day when energy usage is at its highest. Energy storage can shave off and lower the top of the peak, but it also widens it. As a result, a larger, more expensive storage system is required to further reduce the system energy needs.

The following chart, prepared by an Xcel Energy engineer, illustrates this problem. The gray line represents a single day of energy demand for one of our operating companies. Suppose that a 250 MW battery with four hours of storage capability (i.e. 1000MWh) is added to the system. It will shave off the top of the peak, deploying its energy over a five hour period. This analysis assumes that the battery will extend the hours in which it is available to discharge to the system from four to five hours, but doing so requires it to discharge energy during at least some of the hours at a capacity less than its 250 MW maximum. In effect, the battery reduces its maximum capacity in order to be available for more hours. The result is a lower, wider peak –

more like a plateau. The next tranche requires more energy spread over more hours to gain the same effect – in this example, a total of 750MW of four hour batteries (3000MWh) that are deployed over a seven hour period. Because the top of the plateau is wider, the batteries must reduce their maximum capacity by a greater amount in order to be available for the full seven hour period. The final tranche – a total of 1500MW of four hour batteries (6000MWh) – is deployed over *nine* hours. In this final case, the effective capacity is significantly reduced to cover the many hours of need.

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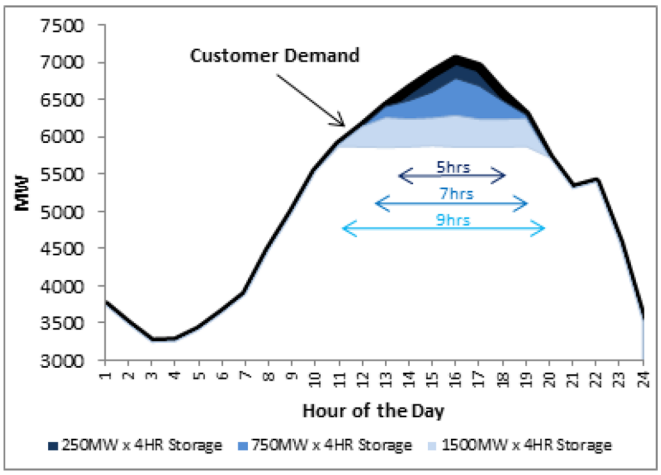



This chart shows that more batteries with longer duration and lower capacity are required at each step to reduce the peak. At some point, it is not technically or economically feasible to continue to use storage to shift energy from off-peak to on-peak periods.

*Stacking storage values*. As I testified above, storage provides multiple values, each of which can enhance the operation and efficiency of the grid. Adding multiple values together – "stacking" – can make the storage resource more valuable as a whole. For example, a storage

resource that provides voltage support and renewable integration will be more valuable than a storage resource that provides only one of these benefits. As the cost of storage continues to decline, stacking these benefits together increases the probability that a utility would choose to add a battery or other storage resource to its system.

At the same time, in determining the value of a storage resource, its multiple potential benefits should not be added if one value precludes another. A battery may simultaneously provide voltage support and frequency regulation, but it cannot, for example, simultaneously integrate renewables and provide black start capability. In the latter case, the battery must be available to restart the system, and it may not be available to do so if it has been discharged to integrate renewables. Thus, before stacking the values of a storage resource, the utility must first determine if it is appropriate to assume those values are simultaneously available.

Together, the problems of seasonality of renewable production, diminished value of peak demand shifting, and stacking demonstrate that, despite its promise, storage still has challenges. Storage is still a valuable resource, one that will be more valuable with technology advancement and careful deployment. In other words, it will be enhanced if it is deployed wisely with good public policy.

**6. Federal support for storage research and development, incentives, and permitting will encourage states and utilities to bring the benefits of storage to electric consumers.**

Congress should take an active role in the development of new energy storage opportunities. There are three key areas in need of federal action: (1) research and development; (2) incentives; and (3) supportive infrastructure and policies. States and utilities will inevitably

choose the resources that make the most sense for their system and customers, but they cannot lead in the same way as the federal government in driving new technology into the marketplace.

***Research and Development.*** Federal energy storage research and development should be part of a broader clean energy research agenda focused on zero-carbon, dispatchable technologies. The nation needs a broad suite of these clean, dispatchable technologies if it is to achieve significant carbon emission reductions at a reasonable price. In fact, Xcel Energy's long-term carbon-free aspiration depends on the development of these technologies.

A federal research and development agenda for storage should focus on increasing storage duration and reducing its cost. In our business, scale matters, and that is true for storage as well. Research should focus on grid-scale storage that is most likely to provide benefits to customers at the lowest cost. The federal research agenda should be developed in concert with the utility industry – after all, utilities are in the best position to understand and maximize the value of different storage attributes, including the value of improving operational control of storage resources.

While lithium ion batteries are the dominant technology in the battery storage industry today, a federal research agenda should target those technologies that have the greatest potential to address long-term system needs and reach commercialization. Those technologies include pumped storage, flow batteries, compressed air energy storage, and other forms of mechanical, thermal and ice storage. The federal research agenda should also encourage the development of hydrogen and other power-to-gas technologies that have the potential to link renewables and other sources of clean electricity to the rest of the economy and dramatically increase the amount of energy storage capacity in the nation.

***Incentives.*** Incentives, including tax credits and federal grant funding, have always played a role in moving new technologies to commercialization. We believe incentives for energy storage, if properly designed, could play a similar role. We appreciate the leadership of Senator Heinrich, Senator Gardner, Senator Wyden, and others on this committee to evaluate new tax incentives to support energy storage investment. These kinds of incentives could encourage even more investment in new storage technologies if companies like Xcel Energy have more efficient options to use them. We encourage Congress to ensure that additional tax incentives enable efficient monetization by utilities or any others.[9]

***Supportive Infrastructure and Policies.*** Congress can also encourage the development of new storage projects by streamlining project permitting and siting and encouraging common standards for the integration, operation and cybersecurity of grid-scale storage systems.

We appreciate Congress's effort last year to streamline the Federal Energy Regulatory Commission (FERC) hydro and pumped storage permitting process with America's Water Infrastructure Act.[10] However, Congress has an opportunity to improve on that legislation. The two year permitting window in that Act only applies when an application is filed and does not address pre-filing licensure. We recommend Congress streamline the pre-license review and determine whether FERC would need additional resources to implement these permitting reforms.

***State leadership.*** With federal support for deployment of commercial storage resources, states will be well positioned to ensure their entry into the marketplace. At least seventeen

[9] Xcel Energy supports proposals to provide for more efficient monetization of energy credits than is the case with the tax equity partnerships commonly used today. Specifically, we support proposals to allow the transfer of energy tax credits to project partners – an approach already employed under some of the clean energy credits. We also support the creation of "American Energy Bonds", under which bonds could be issued to finance investments in clean energy infrastructure with the interest on those bonds paid for using existing tax credits.
[10] America's Water Infrastructure Act of 2018, https://www.congress.gov/bill/115th-congress/senate-bill/3021

states, most recently Minnesota, have adopted energy storage policies that either set targets, create financial incentives, allow utilities to own storage, or require storage to be included in Integrated Resource Plans (IRPs)[11]. This trend is likely to continue, and policy will be a major driver of how the storage market develops. It will be important to manage risk and avoid policies that result in unintended consequences like cost-shifting and cross-subsidization between customers.

Utilities, working with their regulators and policy makers, are closest to the electric system and best understand the value and deployment challenges. Congress and federal agencies should defer to states on the issues unique to their expertise.[12]

**7. Conclusion**

On behalf of Xcel Energy, I appreciate the opportunity to testify before you today to discuss storage and its future on the grid. Storage is already becoming an important part of the electric system. It will play a growing role as we pursue our ambitious carbon reduction targets. We look forward to working with Congress and the storage industry to advance the technology and help overcome the barriers to greater storage deployment.

[11] Edison Electric Institute Energy Storage Trends and Key Issues, http://www.eei.org/issuesandpolicy/Energy%20Storage/Storage_Key_Trends_Solutions_March_2019%20(002).pdf

[12] For example, FERC recently issued Order 841, addressing the role of storage resources on the wholesale electric system. Under Order 841, state commissions are preempted from making decisions about how storage resources connected to the distribution system or behind the customer's meter participate in wholesale markets. We are concerned that the Order does not properly recognize states' role in regulating retail sales of electricity and ensuring distribution system reliability.

The CHAIRMAN. Thank you, Mr. Fowke.
Mr. Kumaraswamy.

**STATEMENT OF KIRAN KUMARASWAMY, VICE PRESIDENT, MARKET APPLICATIONS, FLUENCE**

Mr. KUMARASWAMY. Good morning, Chairman Murkowski, Ranking Member Manchin and distinguished members of the Committee. My name is Kiran Kumaraswamy, and I am the Vice President of Market Applications at Fluence. I also serve as a Member of the Board of Directors for the Energy Storage Association, the leading national voice of the United States energy storage industry. I am honored to testify in front of you today.

Fluence is an energy storage technology and services company jointly owned by Siemens and AES Corporation. Fluence combines the engineering and service capabilities of AES and Siemens energy storage teams.

Energy storage is on the cutting edge of the global energy transition. Bringing increasing amounts of solar and wind power onto the grid means planning for a system in which high levels of power quality are still essential but variability of generation is the norm. Energy storage helps us to meet such challenges.

With the introduction of energy storage, we can, for the first time, shift and control with pinpoint accuracy the time and location of power delivery. A few key points to note here.

First, energy storage unlocks value in all grid assets by improving their utilization—be it traditional thermal plants such as gas or nuclear, renewable resources such as wind and solar or the transmission and distribution infrastructure that delivers energy to factories, homes and offices.

Second and of equal importance for the U.S. economy, energy storage gives large energy users control over their energy costs by allowing them to decide when to use grid power or their own reserves.

Third, the addition of battery storage to gas turbines helps such traditional generators of electricity become more flexible and helps manage the gaps between power demand and supply reliably.

Storage providing peaking capacity is gaining traction broadly across the U.S. Increasingly, utilities are examining and selecting large-scale energy storage in lieu of new natural gas plants to provide for periods of peak demand. We believe one of the most transformative uses for energy storage will be in the transmission and distribution sector allowing utilities to defer or avoid entirely investments in traditional wires solutions.

As the economic, environmental and resilience benefits of energy storage are becoming widely accepted, policy must continue to evolve to ensure storage can compete on a level playing field.

The first area of focus is to accurately measure the capacity value of different durations of energy storage in regional power markets. Many of the underlying modeling techniques for assessing the capacity value of energy storage were developed within the U.S. Department of Energy's National Renewable Energy Laboratory, or NREL. This work is a prime example of how DOE's national labs and other research initiatives have provided expertise and support

that have been essential to and are still vitally needed for the growth of our industry.

A second critical need is to remove barriers to energy storage being deployed as a transmission asset. A regulatory construct for storage-as-transmission is largely undeveloped which is having a direct impact on the ability to install storage for transmission reliability purposes. Our request is for Congress to direct FERC to open dockets on storage-as-transmission started with either technical conferences or notices of inquiry to inform any potential rulemakings FERC may determine are merited.

A third critical need is to take advantage of the unique resiliency benefits that energy storage provides in disaster response and infrastructure planning. To this end, the Department of Energy could provide significant support in studying and quantifying the value of resilience that energy storage provides to the entire electric network.

While we push hard for progress in each of these critical needs, we also want to recognize the accelerating progress that we have made at the federal and state levels. At the federal level, FERC Order 841 has injected much needed guidance for wholesale power markets to adapt to allow energy storage to compete with other traditional resources. We applaud FERC for reaffirming Order 841. At the regional level, we are very encouraged by the progress made in various states like New York, Nevada, New Jersey, Oregon, Maryland, California, Massachusetts and Colorado.

The U.S. currently is the leader in battery storage deployments globally with several countries closely following behind. Removing structural barriers in wholesale power markets, improving regional planning processes and providing certainty for this industry will continue to help us retain that leadership position.

Chairman Murkowski, thank you for the opportunity to be here today. I am happy to take any questions.

[The prepared statement of Mr. Kumaraswamy follows:]

FLUENCE
A Siemens and AES Company

Kiran Kumaraswamy
Vice President, Market Applications
Fluence

June 4, 2019

**Testimony of Kiran Kumaraswamy, Vice President, Market Applications at Fluence, Before the U.S. Senate Committee on Energy and Natural Resources Hearing to Examine Expanded Deployment of Grid-Scale Energy Storage**

Good morning, Chairman Murkowski, Ranking Member Manchin and Distinguished Members of the Committee. My name is Kiran Kumaraswamy, and I am the Vice President of Market Applications at Fluence, a Siemens and AES company. I also serve as a Member of the Board of Directors for the Energy Storage Association, the leading national voice of the United States energy storage industry. I am honored to testify before you today on the topic of grid-scale energy storage and its current and future role in the nation's electricity system.

**Background on Fluence**

Fluence Energy, LLC (Fluence) is an energy storage technology and services company jointly owned by Siemens AG and The AES Corporation (AES). Fluence combines the engineering, product development, implementation and services capabilities of the AES and Siemens energy storage teams. We are currently engaged in an aggressive expansion of the business, backed by the financial support of our two parent organizations.

The market for energy storage is accelerating quickly. Utilities, developers and large energy users worldwide recognize the value of energy storage as critical infrastructure providing superior economic value compared with alternative options, as well as greater reliability, resilience and efficiency to their electric power systems. Customers are calling for industrial-grade energy storage solutions, along with power. Fluence has been developed as a trusted partner to answer the needs of utilities, developers and large energy providers, and to deliver the most comprehensive set of custom-built energy storage solutions and services globally.

Fluence's sole focus is accelerating the speed and guiding the direction of the transformation of global energy networks. Backed by the insights, reach and scale of Siemens and AES, we are creating a new generation of solutions and services. Our

FLUENCE
A Siemens and AES Company

vision and strategy are based on prioritizing lasting partnerships, enabling users to have input into their energy choices, and supporting the entire power ecosystem in bringing us to a sustainable future.

**Energy storage is on the cutting edge of the global energy transition**

The success of Fluence – and the growing energy storage industry we are a part of – puts us on the cutting edge of a global energy transition that is now unstoppable. Energy storage technology is proven, scalable and expanding rapidly to meet a range of critical needs on global electric power grids – grids which are now evolving to meet the complex needs of the 21st century.

Even as countries around the world are transitioning from centralized power systems to decentralized and renewable power, they face significant challenges, often due to aging infrastructure. Bringing increasing amounts of solar and wind power onto the grid means planning for a system in which high levels of power quality are still essential but variability is the norm.

Energy storage allows us to meet such challenges – and transform them into opportunities -- by making better use of all the electricity generation and infrastructure assets we are putting on the grid and those we already have in place. With the introduction of energy storage, we can, for the first time, shift and control, with pinpoint accuracy, the time and location of power delivery. We can improve system utilization and efficiency, and right-size large, fixed-cost investments that customers typically pay for over 20-30 years. The economic value energy storage creates is proving compelling to customers worldwide and is driving the rapid scale-up of the energy storage industry.

In its recent "35x25" report, the Energy Storage Association estimates that by 2025, the U.S. will have 35 gigawatts (GW) of additional energy storage on the grid.[1] Such market growth could provide more than $4 billion in operational cost savings, while creating more than 167,000 jobs, the report says.

These figures are impressive and ambitious, but they also underline a few key points:

First, energy storage unlocks value in all grid assets by improving their utilization – be they traditional thermal plants such as gas or nuclear, renewable sources such as

[1] http://energystorage.org/vision2025

wind and solar, or the transmission and distribution infrastructure that delivers energy to factories, homes and offices. Energy storage is particularly essential to achieve the full potential of renewable energy in the U.S. and around the world, and to ensure all customers can benefit from the economic and environmental advantages of renewable energy. Specifically, energy storage adds much-needed capacity, ensuring power will always be available to meet peak requirements. Storage can also manage short-term variability across the system, providing grid-stabilizing services in milliseconds, and flexibility that is significantly more valuable than even the fastest gas turbines in the market today.

Second and of equal importance for the U.S. economy, energy storage gives large energy users control over their energy costs by allowing them to decide when to use grid power or their own reserves. Further, storage can help protect businesses and other customers from demand charges and variable energy rates. It can also boost resilience, operating in “island” mode to protect business and residential customers against outages and the resulting potential for lost revenue and equipment damage.

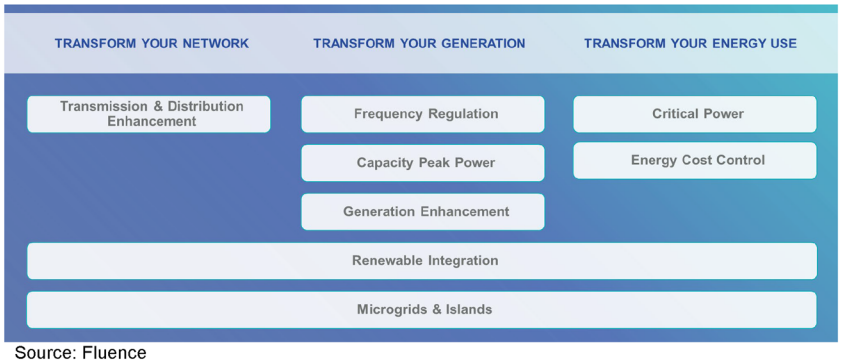
Third, addition of battery energy storage to gas turbines helps such traditional generators become more flexible and provide the higher value and faster-responding grid service known as spinning reserve. In these cases, energy storage fills the gaps between supply and demand, ensuring the reliable and efficient delivery of electricity and often avoiding the need to burn diesel fuel in generators, the predominant source of fuel in remote areas. Such hybrid approaches of adding storage to gas-based resources are continuing in the US and across the world, resulting in lower fuel use and emissions. Deploying battery energy storage also provides significant value on small grid systems located on islands, or in remote or isolated areas like those in northern Chile, where AES has deployed three energy storage systems. They work in concert with conventional generation sources to provide grid stability, responding instantly to disturbances in the grid, such as when a large power plant or transmission line suddenly stops working.

**Flexible Applications for Battery Energy Storage**

As noted above, the range of applications for energy storage – its flexibility – makes it unique. That is, unlike many single-use, fractionally utilized capital assets in our electric power system, individual storage systems can serve a variety of functions on the electric grid. Fluence delivers solutions that provide eight different applications,

and each of our technology platforms has been designed to stand up to the rigorous needs of these industrial applications.

The figure below details the eight applications our systems can provide today, ranging from real-time, split-second frequency regulation to longer duration support for transmission and distribution systems. The following subsections include brief case studies of relevant, real-world projects provided by Fluence, either already in operation or under construction.




Source: Fluence

***Storage Providing Peaking Capacity Gaining Traction Broadly Across the U.S.***

California utilities have been at the forefront of a growing trend to use energy storage – rather than traditional natural gas plants – to provide flexible "peaking" power at times of high demand.

In 2014, Southern California Edison (SCE), one of the largest utilities in the U.S, was facing the retirement of older, natural gas-fired power plants and the unexpected retirement of a large nuclear power plant. To select new sources of capacity to meet customers' needs, SCE ran an all-source procurement process in which energy storage was able to compete against gas-fired generation, demand response and other resources. The result: Based primarily on costs and benefits, SCE awarded AES the nation's first long-term contract for a battery energy storage facility to provide peaking capacity.

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Located in Long Beach, the Alamitos energy storage facility is set to break ground later this month and will be able to provide 100 megawatts (MW) of power for four hours. This project demonstrates the economics, scale and technological maturity of battery energy storage to meet electric system needs.



Rendering of 100 MW AES Alamitos Energy Center – Long Beach, CA

Then in 2016, a critical natural gas storage facility providing peak reserve capacity near Los Angeles had to be taken out of service. The California Public Utility Commission (CPUC) quickly directed investor-owned electric utilities in the affected region to fast-track additional energy storage projects to shore up energy reliability. In response, San Diego Gas & Electric (SDG&E) expedited ongoing negotiations and contracted with AES Energy Storage (now part of Fluence) to build two projects for a total of 37.5 MW of four-hour duration battery energy storage. Located in Escondido and El Cajon, the projects were online in eight months. The 30-MW facility in Escondido remains one of the largest battery storage installations in North America.

SDG&E has already contracted with Fluence for a larger, follow-up project, a 40-MW, four-hour duration installation in Fallbrook, which will be part of an 83.5-MW portfolio of additional four-hour energy storage.

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30 MW SDG&E Advancion Energy Storage Facility – Escondido, CA

When looking at the entire U.S. energy storage market, it is abundantly clear that energy storage is being trusted for bulk infrastructure outside of California. Increasingly, generation-owning utilities are examining and selecting large-scale energy storage in lieu of new natural gas plants to provide for periods of peak demand. In February 2019, Arizona Public Service announced that it had selected 850 MW of energy storage in a head-to-head economic competition against a range of new natural gas peaker plants. In January 2019, Hawaiian Electric announced seven solar-plus-storage projects to provide peak capacity totaling more than 260 MW. And in March 2019, Florida Power & Light announced what is currently the world's largest planned battery, over 400 MW, to provide peak capacity in conjunction with solar.

The chart below shows a selective sample of utilities that have identified storage in their Integrated Resource Plans (IRP).[2] Our focus is to continue to accelerate utilities' adoption of energy storage as an essential component in their resource planning toolkit.

| Utility | State |
|---|---|
| Arizona Public Service | AZ |
| Salt River Project | AZ |
| Tucson Electric Power | AZ |

[2] Not a comprehensive list, only meant to illustrate examples of select utility IRPs.

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| | |
|---|---|
| Southern California Edison | CA |
| Pacific Gas and Electric | CA |
| San Diego Gas & Electric | CA |
| Xcel | CO, MN |
| Florida Power & Light | FL |
| Georgia Power | GA |
| Hawaiian Electric | HI |
| Indianapolis Power & Light | IN |
| Kentucky Power | KY |
| Consumers Energy | MI |
| NV Energy | NV |
| El Paso Electric | NM |
| Duke Energy | NC |
| Pacific Power | OR |
| Portland General Electric | OR |
| Dominion Energy | VA |
| Appalachian Power | VA |
| Puget Sound Energy | WA |
| Avista | WA |

Source: Energy Storage Association

***Storage Providing Transmission and Distribution Services***

Fluence believes one of the most transformative and valuable uses for energy storage will be in the transmission and distribution sector, allowing utilities to defer or avoid entirely investments in fundamental grid assets such as wires, poles, transformers and substations. Looking ahead, these applications will allow utilities and their customers to get the most efficiency, flexibility and resilience from the transmission and distribution lines they already have and use.

For example, Arizona Public Service (APS) recently partnered with Fluence to become one of the first electric utilities in the country to use energy storage to avoid the need to rebuild 20 miles of transmission and distribution poles and wires. The project placed in service last year was designed to serve the small town of Punkin Center, 90 miles outside of Phoenix, where peak electricity demand is increasing. By placing a relatively modest-sized battery array at the end of the last segment of the 20-mile power line, APS has saved its customers the cost of rebuilding those lines, which lie over difficult terrain.

Energy storage is also playing an increasingly important role in regional transmission planning processes in organized markets across the country and around the world.

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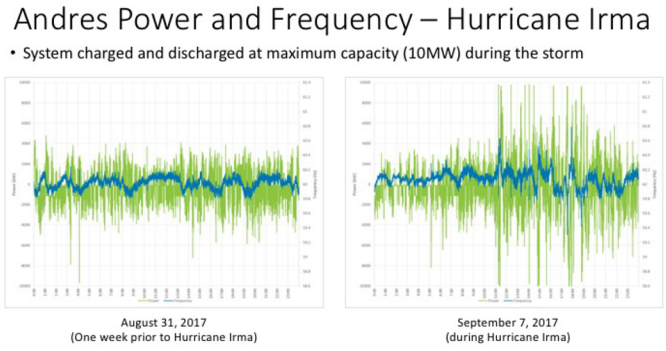
Regional market operators across the country including California Independent System Operator (CAISO), Midcontinent Independent System Operator (MISO) and PJM Interconnection (PJM) are actively studying projects proposed as transmission assets or investigating storage as a potential transmission asset.

***Storage providing frequency regulation and adding system resilience***

Energy storage also adds resilience to electric grids, helping them to both minimize and recover from outages during severe weather events. When the Dominican Republic was hit in September 2017 by Hurricanes Irma and Maria – Category 4 and 3 storms, respectively – AES had just deployed two 10-MW energy storage arrays on the island's grid. As each hurricane approached the island, the grid operator requested that both systems be kept online to support the grid as it managed the wild fluctuations in frequency experienced during the storm, as illustrated below. Both storage arrays responded as intended and helped keep the grid operating throughout the storm, even with 40-55 percent of the Dominican Republic's generation assets forced to shut down.




Source: Fluence

**State and Federal Policy Can Remove Barriers to Energy Storage**

As the economic, environmental, and resilience benefits of energy storage are becoming widely accepted, policy must continue to evolve to ensure storage can compete on a level playing field. We are happy to see the progress exhibited by policymakers at the state, regional and federal levels thus far to remove these barriers, and we see several additional areas to focus on going forward.

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Accurately measuring the capacity value of different durations of energy storage is one critical need to flag. Traditional capacity techniques are unable to measure the value of duration-limited resources such as energy storage, because traditional generators are not duration-limited. However, today leading regional transmission operators (RTOs), independent system operators (ISOs), and utilities are deploying modeling techniques to examine questions such as "how many gigawatts of 4-hour energy storage can I deploy in my system to directly reduce my net peak demand." New York ISO, for instance, has assigned 4-hour energy storage a 90% capacity value, and 6-hour energy storage a 100% capacity value, based on this type of detailed assessment of its system needs. CAISO and the Southwest Power Pool (SPP) have also assigned 4-hour energy storage a 100% capacity value. Recent modeling published by the Energy Storage Association shows similar capacity value is justified in PJM for multiple gigawatts of 4- and 6-hour duration energy storage, though under PJM's current proposal, 4-hour energy storage would only receive a 40% capacity value.

Many of the underlying modeling techniques for assessing the capacity value of energy storage were developed within the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL). This work is a prime example of how DOE's national laboratories and other research initiatives have provided expertise and support that have been essential to – and are still vitally needed for -- the growth of our industry. We are heartened to see bipartisan efforts to advance grid storage technology development and demonstration, such as through the Promoting Grid Storage Act of 2019 introduced by Senator Smith[3] and the Better Energy Storage Technology (BEST) Act introduced by Senator Collins and Senator Heinrich.[4]

A second critical need is to remove barriers to energy storage being deployed as a transmission asset. The Federal Energy Regulatory Commission (FERC) Order 841 is providing a pathway to remove barriers to energy storage's participation for generator services in wholesale markets. But it does not provide a pathway to ensure energy storage is included in regional transmission planning. FERC has weighed in on this initially via Order 1000, which created a mechanism by which alternatives to transmission wires, including local energy storage, can be proposed as a part of regional transmission planning processes. However, to date, consideration of storage

[3] The bill is supported by Senator Collins, Senator Hirono, Senator Duckworth, Senator Cortez Masto, Senator Stabenow, Senator Heinrich, Senator Gardner, and Senator Hassan.
[4] The bill is supported by Senator Collins, Senator Heinrich, Senator Gardner, Senator Smith, Senator Coons, Senator McSally, and Senator King

options in transmission planning has been minimal. A regulatory construct for storage-as-transmission is largely undeveloped, which is having a direct impact on the ability to install storage for transmission reliability purposes. Our request is for Congress to direct FERC to open dockets on storage-as-transmission, starting with either technical conferences or notices of inquiry to inform any potential rulemakings FERC may determine are merited.

A third critical need is to take advantage of the unique resilience benefits that energy storage provides in disaster response and infrastructure planning. To this end, the Department of Energy could provide significant support in studying and quantifying the value of the resilience that energy storage provides to the electric network. While many grid operators, and state and local governments are examining energy storage for resilience, the lack of defined methods for valuing resilience limits the ability to factor such value into cost-benefit analyses that inform resilience planning, and cost-benefit analyses used in budgeting and procurement decisions.

One concrete pathway to accelerate the development of energy storage in the U.S., and to compensate it for the resilience and reliability benefits it provides, is to include energy storage as an eligible technology for the Section 48 and 25D investment tax credit. To that end, we urge the passage of the bipartisan Energy Storage Tax Incentive and Deployment Act (S.1142 and H.R.2069). Doing so would remove constraints to storage project development while enabling both standalone storage as well as all storage co-located with grid assets – gas plants, wind plants and others – to benefit from the addition of energy storage to the electric system.

While we push hard for progress on each of these critical needs, we want also to recognize the accelerating progress at the federal, regional and state levels. At the federal level, FERC Order 841 has injected needed guidance for wholesale markets to adapt to allow energy storage to compete. We applaud FERC for reaffirming Order 841. At the regional level, we are very encouraged by the progress made in New York to accurately recognize the capacity value of energy storage. We are also pleased by the MISO's commitment to examining pathways to include storage in transmission planning, and CAISO's success in weighing energy storage for transmission needs. At the state level, we applaud the passage of regulatory reform in Colorado to ensure energy storage is included in both generation and transmission planning and procurement. Nevada, New Jersey, New York, Massachusetts, Oregon and California have all established, or will soon establish, state-level targets and timelines for energy storage deployment, which have been major catalysts for the industry. And Maryland has done

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innovative work in testing ownership and wholesale market participation models. We believe the leadership demonstrated here provides lessons and best practices for other states to follow. Fluence is among the many industry participants committed to supporting these practices, and helping ensure energy storage is deployed rapidly, smartly and to the benefit of all Americans.

The U.S. currently is the leader in battery storage deployments globally with countries like Korea and China closely following behind. Removing structural barriers in wholesale markets, improving regional planning processes and providing certainty for this industry will continue to help us retain that leadership position. Fluence currently has projects deployed or awarded in 18 countries, from the U.S. and Canada to India and Australia, and we continue adding new employees almost weekly.

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

Thank you.

The CHAIRMAN. Thank you.
Mr. Ott, welcome.

**STATEMENT OF ANDREW L. OTT, PRESIDENT AND CEO, PJM INTERCONNECTION**

Mr. OTT. Thank you, Chairman Murkowski, Ranking Member Manchin and members of the Committee.

I am Andrew Ott. I am the President and CEO of PJM Interconnection. I was before you last October to talk about system restoration and Blackstart, and I am honored to be invited back to talk about the important issue of energy storage.

PJM operates the largest bulk power grid in the nation, the largest electricity market in the world, population of 65 million people. Our role is three-fold: essentially to ensure reliable grid operation, to operate competitive markets that essentially yield benefits for competitive investment to consumers and to the economy, and also, of course, infrastructure planning to ensure the grid remains robust and reliable into the future.

Today, I want to underscore a few points on energy storage that are key, I believe. The first is, again, storage is a flexible, very valuable resource to the grid. We've seen that in PJM. The second point, our markets have worked well to incentivize and incorporate storage. And in fact, we are compliant with the FERC Order 841. It was certainly—our competitive markets have already yielded benefits to incent investment in battery storage to provide certain grid services.

Again, because of our early leadership in this area, we have become the largest market for battery technology that currently exists. We have 300 megawatts of batteries today that participate in our market and provide, primarily, frequency regulation. We also have 5,000 megawatts of pumped hydro storage and one, of course, 20-megawatt flywheel that's still operating in the market.

In 2018, 27 percent of the frequency regulation, on average, every hour in our market is provided by battery storage, by storage devices. Effectively, five years ago it was 100 percent, you know, regular generation. Today, over a quarter is provided by these alternative technologies. Very big success story. At some times, over 49 percent of the total in peak times of the total frequency regulation is provided by battery storage.

One of the largest battery deployments in the nation is in West Virginia at Mount Laurel, West Virginia, 32 megawatt batteries colocated with a wind farm. We have about 1,000 megawatts of new storage in the transmission interconnection queue. We also have about 2,000 megawatts of combined energy storage in renewables.

A third point I would make though, is energy storage, at this point, cannot replace traditional generation like nuclear or coal-fired, gas-fired power plants, but it can, in fact, and has, competed successfully to provide grid flexibility services and very high quality value-added services on the grid.

Obviously, PJM is an independent and fuel neutral organization. Our markets have already been adapted. We allow participation at 100 kilowatts. So we have a tremendous number of distributed resources in our system, in fact, 205,000 distributed generators already operating in PJM's grid today.

Generally, battery storage has limited duration. We have seen about 15 minutes, some up to four hours. The technology is always improving. We have already seen, through our markets, demand response has already significantly flattened the peak of the demand on a day-to-day basis. We don't really have those sharp peaks anymore because of the advent of these technologies coming in. So we need more and more of these types of resources. Aggregation, we believe, is the key to having these types of resources continue to provide competition in this area.

There are a variety of policy issues that impact further incorporation of energy storage. I'd like to point a few of those out. We certainly need some help from FERC. As usual, I am here asking you to help us get some answers out of FERC.

Certainly, reserve pricing. We put a comprehensive proposal in front of FERC to actually price reserves throughout the market. So this is like a 10-minute reserve, 30-minute reserve, tremendous revenue stream potential for battery storage, for other types of storage technologies to give a revenue stream. But we really need those rules to be in place and operational. We will have the same kind of success we have seen with frequency regulation.

Subsidies, again, we will respect the right of Congress and the states to subsidize resource—we need some guidance though from FERC on how that interplays with competitive investment.

Federal/state coordination is also something key. We have already seen 2,000 megawatts of distributed resources in our system, but some help on this notion of how the retail and the wholesale interface.

Energy storage, again, is a transmission asset, some guidance there, as my colleagues on the panel had said.

And finally, again, I think storage does create a tremendous opportunity to use alternative technologies to displace traditional types of resources and clean up, if you will, the grid.

I look forward to your questions. Thank you very much.

[The prepared statement of Mr. Ott follows:]



United States Senate Committee on Energy and Natural Resources,
Testimony of Andrew L. Ott, President and CEO, PJM Interconnection

**"Full Committee Hearing to Examine Expanded Deployment of Grid-Scale Energy Storage"**

June 4, 2019

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## Executive Summary

For many years, PJM Interconnection has been ensuring nondiscriminatory access to the transmission grid and has established competitive markets where all resources compete on a level playing field to serve customer needs. We have helped bring about the vision of open access and competition that this Committee put forth in 1992 with the passage of the 1992 Energy Policy Act by embracing an "all of the above" strategy for resources. This has enabled the PJM markets to serve as a home for innovative new technologies ranging from energy storage to demand response as well as more-conventional resources such as coal, nuclear and natural gas.

PJM has a long history with energy storage in all of its forms and served as an early test bed for incorporating pumped storage hydro, lithium-ion batteries, vehicle-to-grid technology and other forms of energy storage into the wholesale electricity markets. The Federal Energy Regulatory Commission (FERC) recently issued Order 841, calling for full participation by these resources, whether in front of the meter or behind the meter. PJM fully embraces this effort, and in December 2018, PJM submitted to FERC proposed revisions to our Tariff that will continue to evolve our markets to ensure they are open and fair and incorporate energy storage resources without undue burden, while also preserving reliability. We are committed to ensuring that energy storage becomes an integral part of the fabric of a more reliable, more resilient and more cost-efficient power grid.

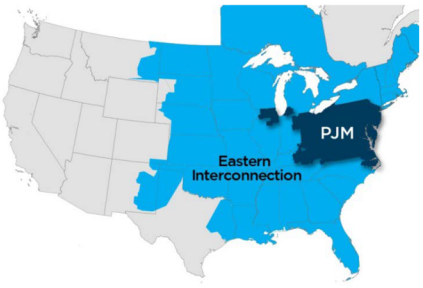
Through this testimony, I also propose certain initiatives for consideration by policymakers, including:

- Improvements in the pricing of all resources that stand by as reserves needed to keep the grid in balance — an initiative we have incorporated into a pending filing with FERC
- Ensuring that state/federal jurisdictional issues associated with energy storage resources connected at the distribution level are resolved smoothly as they have been so far in the PJM region
- Accommodating state and federal subsidies of particular generation resources in a way that does not erode the market's need for an unbiased "all of the above" fair investment signal to attract the resources customers will need to meet their future power demands
- Providing additional guidance that supports the deployment of energy storage resources as transmission assets in those cases where deployment of storage resources represents the most cost-effective and efficient solution to a particular transmission reliability concern

## Energy Storage in the PJM Region: An Overview of Successes and Policy Challenges Going Forward

Thank you for the opportunity to testify today. I am Andrew Ott and I serve as President and CEO of PJM Interconnection. PJM is the regional transmission organization responsible for the reliable operation of the bulk electric power grid serving 65 million people in all or parts of Delaware, Illinois, Indiana, Kentucky, Maryland, Michigan, New Jersey, North Carolina, Ohio, Pennsylvania, Tennessee, Virginia, West Virginia and the District of Columbia. PJM operates the largest bulk power system in the nation, as well as the largest competitive wholesale electricity market in the world.

I'm pleased to testify today to describe:




- PJM's experience integrating energy storage resources into wholesale market operations, including some of the first battery storage resources in the country to access wholesale markets
- The future of these promising technologies in continuing to provide benefits to the power system
- The policy issues and challenges you and other policymakers may wish to consider as energy storage resources increasingly seek to monetize their value in the nation's wholesale electricity markets

## Energy Storage: An Array of New and Existing Technologies

I'd like to start by placing energy storage into context. So often today, when people think about energy storage, they think of batteries — in particular the lithium-ion chemistries that are most prevalent in the market today. And for good reason: The progress made on battery technology in the electronics and automotive sectors has made battery applications in the electric power sector possible, cost-effective and exciting.

But we shouldn't lose sight of the value of diversity in energy storage technologies. On the PJM system, we have several types of energy storage, of which lithium-ion batteries are only one:

- **Pumped Storage Hydro:** PJM has approximately 5,000 MW of pumped storage hydro, including one of the largest pumped storage hydro plants in the world — the Bath County Pumped Storage hydro facility on the border of Virginia and West Virginia. Most of our pumped storage hydro facilities were built decades ago to provide peaking capacity to meet customer demands. These facilities have proven to be highly effective, flexible resources that we integrated into our system years ago and continue to rely upon every day.




**Bath County Pumped Storage Station, the world's most powerful pumped hydro facility. Source: Dominion**

- **Thermal Storage:** Electric storage water heaters participate in the PJM Ancillary Services Markets to help balance the grid in real time. In addition, there are utility programs that use water heaters to peak-shave their load, often based on price signals from the PJM energy and capacity markets. There are approximately 90 MW of aggregated water heater capacity registered to participate in the PJM markets and probably hundreds of

megawatts that provide customer-side peak shaving that activate in response to PJM market signals. These are mostly operated by rural electric cooperatives.

Notably, in 2015 we worked alongside investor-owned utilities, public power and electric cooperatives, with Senator Hoeven and this Committee, to bring about an amendment to the Department of Energy's Energy Efficiency Standards in the Energy Efficiency and Improvement Act of 2015 to recognize the value of this low-cost and ubiquitous energy storage technology. Ironically, had Congress not acted, we were headed toward DOE phasing out the water heater technology used in utility programs, so we are grateful for your support with that needed legislative change.

- **Flywheel Technology:** PJM has one 20 MW flywheel battery in Pennsylvania.

- **Battery Technology:** PJM has 300 MW of mostly short-duration batteries that provide frequency regulation, which helps to keep the grid in balance. These batteries are mostly lithium-ion-based chemistries, although there are a few batteries that employ other chemistries such as sodium-sulfur or advanced lead-acid technologies. These battery resources are in diverse locations — next to high-voltage transmission lines, behind customers' meters, and everywhere in between. PJM markets have also been used as a test-bed for demonstrating and developing nascent electric vehicle-to-grid technology, a novel concept that involves aggregating fleets of electric vehicles that are able to provide services to the electric grid through two-way power flow between the car and the grid.

## A Brief History of the Development of Energy Storage in the PJM Marketplace

PJM's markets have been quite successful in using the forces of competition and innovation to provide electricity both reliably and efficiently to the 65 million customers we serve in 13 states plus the District of Columbia. Our hallmark has been ensuring nondiscriminatory access to the transmission grid and establishing competitive markets where all resources compete on a level playing field to serve customer needs.

In this way, we have helped bring about the vision of open access and competition that emanated from this Committee back in 1992 with the passage of the 1992 Energy Policy Act. And along the way, we have embraced an "all of the above" strategy that has enabled the PJM markets to serve as a home for innovative new technologies, ranging from energy storage to demand response, as well as more conventional resources such as coal, nuclear and natural gas. The policy embraced by



**A two megawatt lithium-ion battery located at PJM's headquarters providing frequency regulation. Source: PJM**

Congress back in 1992, of using market forces to drive new technology and innovation rather than government picking technologies and winners and losers, has served us well over these many years.

PJM has a long history with energy storage in all of its forms. In 2008, PJM was the first to incorporate a lithium-ion battery into its wholesale electricity markets as a source of critical frequency regulation services, in which resources are called upon to respond quickly to ensure the grid remains in balance. This demonstration actually took place through the early deployment of a set of batteries in the parking lot of PJM's headquarters as depicted above.

Those batteries were a "proof of concept" demonstration of the value of batteries in providing real-time frequency regulation service. PJM also worked early on with the University of Delaware to pilot the use of aggregated electric vehicles to provide frequency regulation response through vehicle-to-grid technology. And we have also served as a test bed for use of electric water heaters as an energy storage device, as I mentioned previously.

Those early trials have evolved — today PJM markets provide a revenue stream for a host of innovative technologies and innovative deployment models, including one of the nation's largest battery deployments co-located with a wind farm in Mount Laurel, West Virginia. We allow energy storage technologies and other resources as small as 100 kW to participate in our energy and capacity markets and have seen energy storage technologies team with demand response providers to bid as resources in our Ancillary Services Markets.

I would note that these developments also helped to inform critical policy development at the Federal Energy Regulatory Commission, which issued a series of Orders, under both Republican and Democratic leadership, to open the markets and the grid to innovative energy storage technologies in a nondiscriminatory way. As a result of PJM's early leadership and research, and supportive regulatory action on the part of FERC that recognized the benefits of fast-acting energy storage resources, PJM quickly became the largest market for battery technology over the ensuing years.

## Energy Storage in PJM Today

Today, we have about 300 MW of batteries deployed throughout the PJM region. About half of this total capability (and mostly the larger batteries) are interconnected at the transmission level and thus are both visible and dispatchable by PJM operators to serve the needs of customers. The other half of the 300 MW represent smaller batteries that are deployed at the distribution level in what we would consider to be "distributed energy resources." These could include batteries that are directly connected to lower-voltage distribution feeders or connected behind a customer's meter, such as at a hospital, military base or other commercial customer facility.



**Distributed battery energy storage system at a Microsoft datacenter. Source: Microsoft**

These batteries often have dual uses; in addition to providing wholesale services to PJM, they may be providing voltage support to the distribution network or responding to a customer's time-varying retail rate, for example.

In 2018, on average, 27 percent of the frequency regulation requirement in the PJM system was supplied by energy storage resources — meaning all batteries, flywheels, and pumped storage hydro — and as high as 49 percent of our hourly requirement has been observed. Batteries represent, on average, over 80 percent of the total energy storage resource contribution to the frequency regulation market.

FERC has recently issued Order 841, which calls for full participation by these resources, whether in front of the meter or behind the meter, in Regional Transmission Organization (RTO) markets, to the extent the energy storage resources are technologically able to provide the particular service. Notably, FERC made clear that:

> *"… this Final Rule does not grant undue preference to electric storage resources as a group or to specific electric storage technologies; rather, it removes barriers to their participation, enhancing competition among all resources that are technically capable of providing wholesale services."*[1]

Looking forward, PJM has about 1,000 MW of stand-alone energy storage and about 2,000 MW of combined energy storage and renewables in its generation interconnection queue. Not all resources that enter the interconnection queue ultimately get built. In fact, only 23 percent of the projects that enter the queue ever come online. Regardless, this level of interest serves as a clear indication that markets are working to attract these new resource types and that the development and prospects for energy storage are growing.

## Role of Energy Storage in PJM's Wholesale Markets

PJM is independent and resource neutral. As such, we believe all resources need to be able to compete in the wholesale markets on equal footing. FERC Order 841 directed RTOs and ISOs to make it easier for energy storage to participate in all wholesale energy markets by eliminating undue barriers that may exist and by explicitly recognizing certain physical and technical aspects of energy storage resources.

In December 2018, PJM submitted to FERC proposed revisions to our Tariff that will continue to evolve our markets to ensure they are open and fair and incorporate energy storage resources without undue burden, while also preserving reliability. We had requested that FERC rule on this filing by May 30 of this year, so that we could implement changes by the end of 2019. Although this date has passed, we are hopeful that FERC will act soon on this important matter so that we may work on the modifications to our business systems necessary to implement our filing and give the storage industry greater confidence for investment.

Our filing outlines certain modifications that enhance the ability that energy storage resources already have to participate in our energy, reserve and capacity markets. Although there are a number of technical issues in this filing,

[1] FERC Docket Nos. RM16-23-000; AD16-20-000; Order No. 841, Electric Storage Participation in Markets Operated by Regional Transmission Organizations and Independent System Operators, Issued February 15, 2018.

we are pleased to have received recognition from the American Wind Energy Association and Solar Council that (with the exception of the issue I describe below):

> *"The Clean Energy Entities support many aspects of the PJM Compliance Filing and believe that in general it will lead to more transparent and fair rules for ESRs seeking to participate in PJM's markets."*[2]

One issue that has garnered attention is how energy storage resources can participate in PJM's capacity market and therefore displace a coal, nuclear or natural gas unit to be available on call to provide energy when needed in system emergencies. Consistent with FERC's requirements, we have indicated that battery storage resources *can* be deemed capacity resources and be fully paid to the extent to which they have the duration capability to be available on call when needed. We require the same of a coal, natural gas or nuclear unit, and we require the same of pumped storage hydro or a demand response resource. Our approach is consistent with FERC's directive that the markets need not create undue preferences for energy storage resources but instead must be open to their participation consistent with their "technical capability" of providing the service in question.

Today, in PJM and in other areas of the country, battery duration is generally limited — duration could be anything from 15 minutes to one or two hours (typically never longer than four hours) at their rated capacity before they need to be recharged. However, even with these relatively short durations compared to other resource types on the grid today, we don't exclude these batteries from participating in the capacity market. Instead, short-duration batteries are prorated based on their capability (just as we do with renewable resources) to recognize this limited duration. In short, we are treating batteries comparably to any other resource that seeks to serve as a capacity resource. As capacity resources are integral to ensuring reliability and keeping the lights on, we think it is only fair, as well as consistent with the FERC Order, to pay them comparably to what we would pay a cleared nuclear, coal or natural gas resource when they provide a comparable service.

I would note that the duration requirements for energy storage capacity resources that we submitted to FERC are, in-part, driven by the success that demand response has had in our capacity market. The advent of demand response, in which industrial operations or buildings and other facilities agree to curtail their load during system emergencies, has worked to "flatten" our expected load curve when demand response is called upon. In effect, this has transformed our capacity design requirements from serving what used to be a one-hour "needle" peak demand into a lower, wider but more sustained multi-hour peak demand.

PJM has been a national leader in integrating demand response. Our success in integrating demand response has worked appropriately to notably change our system requirements, a point that we need to recognize as we define when an energy storage resource can serve as a capacity resource and effectively displace a coal, nuclear or natural gas plant.

Nevertheless, we do agree that there are additional opportunities to aggregate batteries in order to meet the reliability requirements of a capacity resource. In this vein, we await the FERC's Order, which is still pending, setting the rules

[2] Protest of the American Wind Energy Association and Solar Council, FERC Docket No. ER 19-469 at p. 2 (February 7, 2019).

for aggregating distributed energy resources such as batteries. Guidance from FERC on the various technical issues associated with aggregating distributed energy resources such as batteries will help to provide further avenues for these resources to participate in our markets. In the interim, the economic signal we will be sending about system needs will help to spur the market to develop longer-duration batteries. This is good for customers, for the industry as a whole and for the nation in terms of enhancing the resilience of the grid.

## Future Policy Issues for Consideration

Currently, there are a host of interwoven policy issues at both the state and federal level that incorporate or impact energy storage in one way or another. I point these out as issues that will come before the FERC, the states and potentially before this Committee through the hearing process. Each of these issues will need to be tackled as we move forward and witness increased technology innovation and deployment of more efficient energy storage resources:

- **Reserve Pricing:** PJM currently has a Reserve Pricing proposal before FERC that is designed to recognize the increasing value of maintaining adequate reserves, particularly as the level of intermittent renewable resources such as wind and solar continue to be deployed. As we know, although renewable resources can have great value, they are dependent on levels of wind and sun that can change on a moment's notice due to changes in wind patterns or cloud cover. Our pricing proposal before the FERC is intended to properly price these reserves and the value they bring to maintaining a stable system. We have recently made this filing but feel it is important for FERC to move forward on these proposals in a timely manner.

- **Subsidies:** An issue has arisen as to how to address government-mandated subsidies to particular technologies (either conventional or new) that have the effect of squeezing out of the market other, potentially more-efficient and cost-effective technologies such as new energy storage technologies.

  We believe the fundamental tenets of the Energy Policy Act of 1992 called for competition across all resources. Subsidies of one kind or another, whether at the state or federal level, only work to distort investment signals and stymie the development of innovative technologies. Although we respect the right of Congress or the states to support different technologies or specific power plants for the jobs or environmental benefits they bring, we think this technology-specific approach ultimately defeats itself by prompting an ever-growing list of new subsidies needed to counter other existing subsidies.

  We at PJM have championed market-based approaches that incorporate desired state and federal policies and have proposed various ways that those state and federal interests can be incorporated into the markets rather than operating outside of them. FERC has a major case on this very issue that has not moved forward for some time. We have asked the Commission to act soon to provide critical guidance in this needed area as both investors and customers depend on the regulatory decisions FERC makes.

- **Federal/State Coordination:** The states and the federal government need to coordinate in order to maximize the value of energy storage resources for both transmission providers and distribution providers, rather than "pigeonholing" technology and rules based on jurisdictional categories of distribution versus transmission. Unfortunately, the Commission's recent Order on integration of storage resources into the wholesale markets has engendered a state versus federal dispute over jurisdiction. Ironically, in the PJM marketplace, we have allowed *with state approval* over 2,000 MW of distributed energy resources to participate in our markets, ranging from small-scale solar photo-voltaics to multi-megawatt natural gas plants. All of these requests have been coordinated with the local distribution utilities and followed state interconnection rules and guidelines. In short, at least in the PJM region, this dispute is something of a "tempest in a teapot" that ignores the realities of our successful integration of 2,000 MW of distributed energy resources into our markets where they can receive the full economic value of their investment.

- **Energy Storage as a Transmission Asset:** We look to policymakers to work with us on the various regulatory principles that would guide incorporation of energy storage resources as rate-based transmission assets. Energy storage resources could, in certain circumstances, be deployed more cost-effectively than building new transmission lines while avoiding the more complicated land-use and permitting issues associated with building a new greenfield transmission line. But there remain details to work through, including whether and how such resources can participate fairly in the markets when they are not being called upon to address a particular transmission constraint, how RTOs can assess the resilience of an energy storage resource co-located at an existing substation when compared with the development of a new alternative transmission line that could reduce the risk of a single point of failure, the cost allocation of such facilities, and myriad other issues. As we see increased interest from PJM transmission owners and merchant developers in this area, PJM is committed to working through these issues with our stakeholders, the states and FERC.

## Conclusion

As FERC Commissioner Cheryl LaFleur recently mentioned publicly, energy storage technologies can serve as a "Swiss Army Knife" for the grid — they can be designed, deployed and controlled in such a way that they can provide multiple different services and reliability needs across the electric power sector: generation, transmission, distribution, all the way down to the residential customer.

In the future, we will see energy storage being deployed to solve transmission upgrade issues. We will see it deployed to provide stability to distribution feeders that have high solar deployment. And we will see it deployed behind customers' meters so that individual customers can potentially respond to dynamic rates and have the ability to improve power quality or ride through a short power outage.

PJM's role will be to ensure that our markets, our transmission planning, and our operations can accommodate these varied use cases so that energy storage can become an integral part of the fabric of a more reliable, more resilient, and more cost-efficient power grid for the future. We look forward to working with this Committee, FERC, states and stakeholders to make this a reality in the months and years to come.

The CHAIRMAN. Thank you, Mr. Ott.

Thank you, each of you, this morning for your contributions. I think it is clear we recognize the benefits that energy storage can bring. I think Mr. Fowke, you said, there is no silver bullet out here, but this is clearly a component piece, one that adds flexibility, one that gives us some room to run here. And understanding how we have really seen a significant increase in energy storage deployment over this past decade here is impressive.

Several of you have mentioned the FERC Order 841. There is also Order 845, designed to improve the interconnection process for energy storage resources.

Mr. Ott, you have outlined some other areas where it would be important to get some guidance or indicators from FERC that would help to clear the regulatory path for energy storage.

In addition to what Mr. Ott has outlined, is there anything else that any of you would suggest that FERC needs to look to with regards to regulatory obstacles that are in the path of further deployment of energy storage?

I will throw that out to any one of you.

Mr. Kumaraswamy and then Mr. Davidson.

Mr. KUMARASWAMY. Sure, I think as I mentioned in my written and the oral testimony, the subject of storage as transmission needs to be studied further, I think that maybe structural deficiencies in the way we actually look at that subject.

It's an area that we haven't seen much traction overall in the market even though we have had the broader construct of Order 1000 that created the pathway for potentially non-wires alternatives to be considered in regional transmission planning processes.

We still haven't seen a lot of success come through from the FERC. And so, I think that may be an area that is worthwhile to do a little more exploration. It could be furnishing notice of inquiries or technical conferences with the right subject matter experts to figure out what issues are being impediments toward deploying storage for transmission and distribution needs.

The CHAIRMAN. Very good.

Mr. Davidson, did you have anything that you wanted to add there?

Mr. DAVIDSON. Yes, ma'am.

Senator, I would like to add Brookfield is the single largest private owner of a FERC hydro license. We deal with FERC and stakeholders around relicensing our facilities on a continuous basis. It's arduous.

However, it is well known, it can take upwards of five years to relicense a single facility, but we know how to do it. We do it well and FERC, in the processes now I'd say that it's like any other process, there's always ways to improve. But I'd say that because we know how to do it and we know the way to go through the process, it works well.

The CHAIRMAN. Let me keep on with you, Mr. Davidson, because you mentioned the length of time for the permitting process, but we also recognize that while pumped hydro storage is the most commonly used form of storage, 95 percent, it is also my understanding that these, any new projects, are almost cost prohibitive.

I am told that on average any new project is $1 billion, averages $1 billion, limited to certain geographic locations and certainly take a longer time.

How do we get around this hurdle because you have regulatory hurdles but you also have economic hurdles?

Mr. DAVIDSON. I think it's more of an economic hurdle right now. I think where the market is today, we don't see the price signals that justify the investment in new pumped storage. So there will have to be some sort of incentives or other ways to encourage that type of investment.

The CHAIRMAN. Well, around this Committee we have been talking a lot about resilience. Mr. Kumaraswamy, you mentioned the importance of storage when it comes to maintaining grid operations during natural disasters. Do you think that storage takes on a, perhaps, a more heightened role in these areas, these parts of the country where they are seeing, perhaps, more disaster prone situations where the economic challenges that you speak of, that we have been having a problem with, can get that more clear market signal because we have to have something that stands as that tempering agent, if nothing else?

Mr. KUMARASWAMY. Absolutely. No, I think that's a great question and I want to give you one example that I've highlighted in the written testimony.

One of our parent companies, the AES Corporation, actually has two, 10-megawatt energy storage areas that they've deployed in the Dominican Republic. If you go back to September 2017 during Hurricanes Irma and Maria, you know, Dominican actually had a significant impact from the hurricanes. And we have actually seen that the storage arrays provide a significant amount of frequency control for the island grid, even though about 40 to 50 percent of the traditional generation has been offline in the Dominican Republic in the same timeframe.

So storage can do that because it is simply the best tool that you have to manage the variations in frequency and it takes a much more important turn when you go into island accounts that have limited resources to actually balance the grid and more so during disaster conditions when one or two of your significant generation sources may be offline for a fuel reason or for different reasons. And so, that is a great point in the sense that the value that storage provides in adding to system resilience is significant.

Again, AES and Siemens have actually provided for a similar plan in Puerto Rico where it's a concept of creating mini-grids in Puerto Rico where you can have solar and storage co-located in a manner that adds significant resilience to Puerto Rico and redesigning and reshaping the overall electric grid in a manner that is much, much more resilient than the current infrastructure.

The CHAIRMAN. Thank you. Thank you, all.

Senator Manchin.

Senator MANCHIN. Thank you, Madam Chairman.

Dr. Crabtree, this might be for you and then anybody else can chime in if they want.

I understand that a potentially serious obstruction of greater adoption of manufacturing for low carbon-free technology is going

to be reliable access to critical minerals. And right now, we depend mostly on China for those minerals.

With the trade war and the instability that we have, how could this thing escalate? How long it could go on? What type of a vulnerable situation are we in in order to proceed further in light of a stable domestic supply? We know we have those minerals here in America. We just don't do the refining or do any of the processing. Do you believe it is of a critical nature that we should be moving and acting quickly?

Dr. CRABTREE. I think that's an excellent question, Senator Manchin, and indeed I do believe that it is critical.

If you look at what other countries have done, primarily China, they have taken a very strategic and deliberate action to line up their supply chains. So they've gone to other countries and written long-term contracts to get lithium, for example, or cobalt.

They bring those minerals to China where they're refined and then sell them to battery manufacturers, some of which are in China, but elsewhere as well.

The United States hasn't taken a strategic and deliberate point of view to that challenge. And I think you mentioned that there are minerals in this country that we can certainly exploit. We should certainly do that. But we'll need many more sources, other than those that are here, and I think we should look at that.

Senator MANCHIN. What happens to be some of our impediments? That basically, is cost, you know, us being in a capitalist market and society that when we start down that path our costs might be a little bit higher, they will undercut us. And it pulls the rug out, unless strategically for our country, we strategically have a supply because of the need that we have and the security of our nation. And I think, I mean, everything that we do, if you are talking about energy—we have what, turbines, lithium batteries, solar cells? Everything depends on it. And we do not produce one ounce.

Dr. CRABTREE. So the point you raise is extremely valid. It will take some time to remedy.

I think your point about being in a capitalist society and the cost being higher is a correct one, and we have to find creative and innovative ways to really bring the cost down.

Senator MANCHIN. Well, our government, DoD, is part of where it has to go in order for us to have a strategic supply.

Dr. CRABTREE. That's an excellent point. There's a lot of things that can happen in the military that then spill over into the civilian area, for sure.

And may I bring up one more point? And that is that recycling can play a role here. We don't recycle our lithium-ion batteries at the moment. Less than five percent are recycled. In fact, DOE just started a new program at Argonne starting in February of this year to look at ways to recycle lithium-ion. And if we can do that——

Senator MANCHIN. Are other countries recycling?

Dr. CRABTREE. I'm sorry?

Senator MANCHIN. Are other countries recycling? Do you know?

Dr. CRABTREE. So far no one in the world has the advantage. It's a level playing field.

Senator MANCHIN. No technology for that yet.

Dr. CRABTREE. There is no technology for it. So, you can smelt and take the elements off. At Argonne and elsewhere people are looking at what's called direct recycling. That means taking the cathode out of the used battery as a unit, refurbishing it and putting it back in.

Senator MANCHIN. Gotcha.

Dr. CRABTREE. This is a way to get the cost down considerably.

Senator MANCHIN. Mr. Ott, if I could, PJM has the largest amount of demand response in the world, currently making up six percent of PJM's total supply. And you have expressed concern that without limits on discharge duration, storage resources may displace these important demand response resources in the capacity market. However, hard critics argue that your proposal prevents storage from fully participating in the marketplace.

What are some of the opportunities for storage participation in PJM beyond the capacity market?

Mr. OTT. Yeah, thank you, Senator.

It is key that, certainly, the revenue streams that have created the significant benefit of, you know, six percent of our resources being demand response is displaced probably the equivalent of like nine nuclear power plants. I mean, it's a significant stock.

The point though is that at some point the peaks become flat and we need to look for alternative ways to use these kinds of technologies. Hence, we've put forth a proposal to say, look, there's tremendous opportunity for a 30-minute reserve, 10-minute reserve, these other types of very valuable grid resources, backup power as you indicate. If we can pay for them and develop revenue streams for those——

Senator MANCHIN. Basically, you want to put those in the recharges.

Mr. OTT. Correct. I want to put those in the market.

Senator MANCHIN. We don't want to camouflage it. We want the consumers to pay for that capacity, but you say it will save them in the long run?

Mr. OTT. Essentially what it would do is create a forward market for these types of valuable reserves and that would create the revenue stream that's needed for further development. And that's really where we need to be.

Senator MANCHIN. What type of a cost increase is that going to be to the average retailer?

Mr. OTT. In fact, what we saw with frequency regulation, it was actually a cost decrease because the competition from the new entry was so great that it actually lowered the total price over time. So, my opinion is it would be, it would actually be a savings over time.

Senator MANCHIN. Okay, thank you.

Thank you, Madam Chair.

The CHAIRMAN. Senator Gardner.

Senator GARDNER. Thank you, Madam Chair and thank you to the witnesses for your time and testimony today. Welcome to the Committee.

I want to compliment Xcel Energy for the work they have been doing on their 2030 plan, their 2050 plan. Your testimony, Mr. Fowke, talked a lot about the work that you have been able to do

to deliver, already, on that vision of both the 2030 as you work toward 2050.

I agree that storage and a number of other energy technologies can be developed collaboratively through public and private partnerships, investments. And so, I will focus my questions on the federal role in that partnership.

You talked about and you called for research and development investments for development of hydrogen and other power to gas technologies. Could you talk a little bit more about how hydrogen can play an important role in achieving these, the goals of the Xcel Energy plan, the clean energy plan?

Mr. FOWKE. Well, thank you, Senator, and thanks for your support in so many things you do.

You know, I know that with today's technologies we can get to that interim goal of an 80 percent reduction. It takes the right public policy, but we can do it.

To get that last 20 percent of carbon out of the big grid, and that's what I'm talking about here is the big grid, it's going to take new technologies. We've talked a lot about the development of storage, but it's going to take, I think also, dispatchable resources and it could be in the form of the next generation of nuclear technology, the next generation of carbon capture or something I probably would have laughed at ten years ago, the development of the hydrogen economy.

And the opportunity to use electrolysis and renewable energy to fund or to power that electrolysis and produce renewable hydrogen or the opportunity to use high temperature steam and nuclear plants to produce hydrogen, again, carbon-free. I think it's a tremendous opportunity. And then that hydrogen could be used in fuel cells or potentially remodified gas plants and then you have your dispatchable resource.

Our approach at Xcel Energy is to be technology agnostic. Utilities aren't really designed to do a lot of R&D. And so, here's where the role of the Government, working with industry, really comes into play. And again, thank you for your support.

Senator GARDNER. Thank you very much.

As one of the sponsors of the Storage Investment Tax Credit bill, along with Senator Heinrich and many other of our colleagues, I am interested in seeing this tax credit spur the adoption of additional energy storage and opportunities.

How can we ensure that the new tax incentives are efficiently used by utility companies and other potential investors?

Mr. FOWKE. Well, that's a really good question. I mean, obviously, the incentives have come a long way into getting us to where renewables will be our biggest source of energy on our system by next year. And I think incentives get a lot of credit for that. But, along the way a lot of participants in the market, including many utilities, don't have the tax appetite to efficiently use those tax credits. So, as you know, Senator, complicated equity partnerships are developed where you basically monetize that through partnership structures. They're complicated and the participants are fairly limited.

So, what does that mean? It means the cost of capital raises. And when the cost of capital raises, the renewable project becomes more

expensive and ultimately becomes more expensive for the consumer.

So, if we can make the utilization of those tax incentives more efficient and have more broader participation, you'd lower that cost of capital. And that's something that we've got some ideas about and we're working with many of you on the Committee.

Senator GARDNER. Thank you. I look forward to continuing our work together on that so we can actually utilize the tools that we have. It is pretty exciting.

Mr. Kumaraswamy, a question for you regarding some of the energy storage work you talked about. I was impressed with the numbers that you testified in your opening statement about estimates for market growth that your company and others in the storage industry will need to grow to meet that demand. Pretty impressive.

I am hearing that there are supply chain issues though and some concerns about those challenges, particularly related to some of the news that have been recently highlighted by the People's Daily, the ruling Communist Party newspaper in China. They ran a commentary last week headlined, "United States don't underestimate China's ability to strike back." It noted that the United States is uncomfortably dependent on rare earths from China. The editorial included this line, "Will rare earths become a counter weapon for China to hit back against the pressure of the United States has put on for no reason at all? The answer is no mystery."

How do companies like yours and others deal with the critical mineral supply chain challenges such as rare earths, graphite, cobalt, nickel and others?

Mr. KUMARASWAMY. That's a great question, Senator.

Fluence is a technology agnostic company, so we actually don't manufacture batteries, we don't manufacture rotors. We have the technology platform that we offer for the customers and we design these solutions in a manner where they can benefit in terms of the performance from those systems and minimizing the total lifetime cost of all of those solutions. And so, what we end up doing is actually working with a broad array of suppliers globally to source many of these components. And so, I think it protects us and shields us from particular exposure in a particular area or a particular region of geography and that gives us the capability to continue to serve our customers globally with the supply chain that we have. So——

Senator GARDNER. Just quickly.

Do companies, storage companies, generally manufacture their own cells, modules, battery packs that integrate the system or do they source most of these from Chinese battery cells and modules?

Mr. KUMARASWAMY. There are companies that actually do that, but there's also a robust supply chain that is non-China based that's actually available in the marketplace as well.

Senator GARDNER. Very good, thank you.

Thank you, Madam Chair.

The CHAIRMAN. Senator Heinrich.

Senator HEINRICH. Dr. Crabtree, I want to ask you a little bit about the nexus between storage and carbon pollution, because one of the things we are trying to get at here, obviously, is to address our climate challenges, and storage can obviously play a role in re-

ducing those emissions, but used in certain ways it can also increase those emissions.

Has JCESR or have you given thought to what policies or market structures might be needed to ensure that as we bring storage on to the grid we are actually having the impact of cleaning the grid up?

Dr. CRABTREE. That is a great question, Senator Heinrich.

I think one of the most important things is that we charge the storage that we put on the grid with clean electricity. So if we're charging with fossil electricity, we're basically encouraging the greater use of fossil electricity.

And I think the ways that we can find, either through policy or incentives at the state level and at the federal level, to encourage that simple activity is the most important thing that we can do.

Senator HEINRICH. Great. I appreciate that.

Mr. Ott, as you are aware, Section 204 of the Federal Power Act bars any utility practice that is unjust, unreasonable, unduly discriminatory or preferential. And as you know, I have been closely following FERC's implementation of Order 841. You said you were compliant with Order 841.

But let me ask, in PJM's filings, can you, I guess, explain to us how putting in place a 10-hour minimum capacity requirement for storage is not on its face unduly discretionary or preferential, and could that potentially actually make PJM non-compliant with FERC's Order 841?

Mr. OTT. Thank you, Senator.

I believe the key here is that we're treating all resources the same for providing the same service. And again, I believe from a capacity perspective, allowing aggregation, allowing resources to come together to meet the requirement is a way that will create a platform, if you will, for resources that currently can't meet duration requirements to actually, I'll say, participate with others. So, there are ways to get there. It's not a barring.

Senator HEINRICH. How did you arrive at that figure, 10-hours?

Mr. OTT. It's based on the duration of our peaks given the tremendous amount of demand response we have in our system.

Senator HEINRICH. Mr. Davidson, I want to ask you a little bit about the historical role of hydropower versus what we may need today and whether or not the structures are there to incentivize the role of hydropower in the future as a grid balancer.

Historically most hydropower has been used for firm capacity. Obviously, we see an enormous role going into the future of what you discussed in your testimony of using hydropower as a grid balancer.

But are there changes that need to be made at the state and federal levels in policy or in market structures to encourage its use in that role?

Mr. DAVIDSON. Yes, Senator, thank you for the question.

The simple answer is yes. Today, hydropower and pumped hydro, in particular, is taking on the job of trying to help mitigate intermittent resources as it comes on during different periods of the day and move that energy during periods when it is most needed. As we continue to integrate even more of these intermittent resources into the system, this need will become even greater.

The economic signals that are out in the market today do not justify the extensive——

Senator HEINRICH. They are not adequate to——

Mr. DAVIDSON. No, sir. They're not adequate for the amount of investment you have to make in pumped-storage.

The one thing you do have to remember though, is when you build a pumped-storage facility, this is a 100-year life asset.

Senator HEINRICH. Sure.

Mr. DAVIDSON. Many parts of it, the mechanical parts of it, are 30 to 50 years, but the actual infrastructure, the pieces, the parts of it we build inside of mountains, they're there, basically forever. So we have to think of these assets are forever assets.

Senator HEINRICH. Mr. Kumaraswamy, I want to get your thoughts on how important—well, a couple of years ago we heard a lot about value stacking. How important is that today and how should state and federal market rules be crafted to reflect the incremental value and the revenue streams from different types of services that storage can provide and potentially provide concurrently?

Mr. KUMARASWAMY. That's a great question, Senator Heinrich, and thank you so much for your leadership on many of the storage-related bills that you've sponsored or you've supported over the years and currently.

On the value stacking we always say that you can make the business case work with two or three different services that are provided in the marketplace. So, in many, many markets across the U.S. what we are finding is that four hours of energy storage is enough to get even 90 percent or 100 percent of capacity current. And so, having the capacity value come through from the regional markets is a significant plus. And then you add the capability for energy storage to provide that peaking capacity and frequency relations simultaneously and that lets you do two of those services at once. And many markets, again, just doing those two things alone will get you over the finish line and that's partly enabled because of the falling cost of energy storage over time also, right?

So I think we have noted that previously in the opening remarks here in this hearing. Energy storage costs have fallen significantly in the last several years. And as far as we can see, that trend is going to continue, not because of anything that we do in the energy sector, but everything that happens in the transportation sector.

And so, whatever is happening on the EV side of the house is really creating that synergy right now that the stationary energy storage market can take advantage of and right on top of that and take advantage of this amazing technology that we have.

So I think in answer to your question, I would say doing capacity and some of the ancillary services really is essential to crossing the line in many of the markets.

The CHAIRMAN. Senator Stabenow.

Senator STABENOW. Thank you, Madam Chair, for another excellent hearing on such a critical topic for all of us. When I hear about the things happening in American innovation, thanks to all of you, it just reminds me over and over again if we could just really focus and get past debating whether or not climate change is real and focus on what we can do about it, there is a lot that we can and

have to do about it. I appreciate the Committee's thoughtfulness in lifting these things up because there is an incredible sense of urgency as we watch the severe weather and past disaster assistance bills over and over again. Thank you for all that you are doing.

Particularly, Dr. Crabtree, I want to ask you a couple questions as Director of the Joint Center for Energy Storage Research. I am very pleased the University of Michigan is a key partner in that. I hear a lot about what you are doing from them, and I know that they play an integral role in research to advance solid-state batteries.

As a state focused on transportation, this is obviously of great interest to me. I understand this technology can significantly reduce EV charging times which is going to be essential as we deploy more and more electric vehicles, and some are saying to as little as 10 minutes which would be fantastic and increase the storage capacity in smaller, simpler battery packs which is also very important. I am wondering how close are we to widespread commercial deployment of this kind of battery technology and what are the challenges to not only getting to commercialization but also production of solid-state batteries in the United States?

Dr. CRABTREE. That's a wonderful question and thank you, Senator Stabenow, for your support. We very much appreciate the University of Michigan who does play a big role both on the transportation side and for the solid-state electrolytes that you mentioned.

Senator STABENOW. Yes.

Dr. CRABTREE. I was at a conference last year of early career battery researchers. There were about 60 of them. And they took a survey and said what do you think is the most important or impactful development that is on the horizon and the number one answer was solid-state electrolytes.

So I feel, personally, that this is something that will happen. We've used liquid organic electrolytes for lithium-ion batteries since their inception in 1991, but so far have not been able to improve on that.

One of the things that solid-state electrolytes would do is dramatically improve the safety of batteries. There's the thermal runaway reaction, which is the problem that Boeing ran into a few years ago and we all know about, occurs. It's a reaction between the liquid organic electrolyte and the cathode. So with the solid-state electrolyte, that side reaction is gone and suddenly the safety is much greater.

You asked to how close are we to that? So the problem, the big technical challenge, is how fast lithium-ions move in the solid-state electrolyte. And most solid-state electrolytes, they move quite slowly which means the charging time would be slow.

There are two classes of materials where they move actually faster than in liquid organic electrolytes and those two classes of materials are getting enormous attention right now. So I would say that it's quite promising that this will happen. Many others as well as myself, feel that it's very likely to happen in the laboratory probably within the next five years and then you face probably another five years of scaling it up and bringing it to production. So my guess, and I may be conservative in this, is that it's probably about ten years away.

Senator STABENOW. Well, we need to figure something out because we need to be moving. I appreciate all your work. We need to be moving as quickly as possible on this.

I also appreciate your testimony on the benefits of electric vehicles and in your written testimony you said, "EVs unite the two largest energy users in the economy, the electric grid and transportation and create a new horizon on the electric grid."

Both Senator Alexander and I have introduced a bill to extend the federal tax credits we need to be able to do that to be able to get more vehicles in the marketplace to be able to bring, sufficiently bring, the price down because of volume, but we also need the charging stations. This is a catch–22 in terms of being able to quickly move forward on that.

I wonder if you could speak just a little bit more about harnessing the energy potential of vehicle batteries for grid services during and after the life of the vehicle. I think the afterlife, the recycling piece is very, very important. Research suggests, as you know, that retired lithium-ion vehicle batteries have as much as 70 percent of their initial storage capacity and potential for discharge of electricity for another seven to ten years in less demanding uses.

You briefly mentioned it. You mentioned the Department of Defense. But I am wondering what your feeling is in terms of being able to move more quickly on recycling of those batteries?

Dr. CRABTREE. So I think this is universally recognized, that recycling is universally recognized as something that's timely and needs to happen badly, partly because EVs will drive the demand for lithium-ion batteries enormously up and we need to look for our supply chain, as Senator Manchin was mentioning earlier, and also the cost.

So, for example, if you take a lithium-ion battery out of a car when it still has 70 percent of its capacity left and put it into the grid, basically cutting the cost by a factor of two for each of those applications because the battery is now being used twice.

At the end of its usefulness for the grid, of course, we have to recycle. And my feeling is that within the next five years with the new emphasis on recycling, that we will find ways to recycle at lower cost and make use of all of the elements, particularly lithium, nickel and cobalt that are in used batteries.

You may know that lead acid batteries are 99 percent recycled. It's actually cheaper to get lead from an old lead acid battery than it is to mine it out of the ground, and we'd like to reach that state for lithium-ion as well.

Senator STABENOW. Thank you.

I have other questions that I will submit for the record, Madam Chair.

Thank you to each of you.

The CHAIRMAN. Thank you.

Senator Hirono.

Senator HIRONO. Thank you, Madam Chair, for continuing to focus on the need to reduce emissions from the use of fossil fuels.

I have a lead up to a question for you, Mr. Fowke. Hawaii is on the leading edge of incorporating renewable power and energy storage. And of course, Hawaii is not connected to any other states' grids, so we are kind of on our own.

I visited the Hawaii solar and storage facility on Kauai island in Hawaii in April. It is the largest combined solar and battery storage facility in the world. It generates 11 percent of Kauai's power and can serve as much as 40 percent of Kauai's evening peak power demand. All together Kauai Island Utility Cooperative gets 50 percent of its power from renewable sources and it expects to reach 60 percent renewable power by the end of this year with another combined solar and battery storage system at Pacific missile range facility, Barking Sands Naval Base.

Hawaiian Electric—which is the largest utility in the state and before Kauai Utility Co-op came along, it was the only utility in the state—recently received approval for six new solar and storage projects to provide 247 megawatts of solar energy with almost 800 megawatt-hours of storage, enough to power 105,000 homes per year while eliminating the use of more than 48 million gallons of imported fossil fuel.

Hawaii was the most imported fossil fuel dependent state in the country and we had probably the highest electricity rates in the country, possibly with the exception of Alaska.

So the company is preparing a second round of bids for even more solar and storage to replace fossil fuel plants, and there will be even more innovation in the future to meet Hawaii's goal of 100 percent renewable power by 2045.

From a utility's perspective, what are the challenges of operating a system with technology solutions that do not have a long history of commercial use and do you think it is important for the Federal Government to reduce the risk of adopting early stage technologies? I recognize that research is really important, but then we really need to figure out how to deploy these technologies in a way that is meaningful. What are your thoughts about the Federal Government's role in the deployment side of things?

Mr. FOWKE. Well, Senator, thanks for the question.

You're absolutely right. Regulated utilities really aren't designed to do a lot of research because their obligation is to pick the most economically efficient resources and put them on the grid. And if there's other economic signals, the price of carbon, et cetera, we factor that into that but experimenting in a large-scale, outside of pilot programs, is difficult. So that's where the Federal Government, I think, comes in to do the research, provide the incentives to make that more affordable so they can be implemented.

You know, your concept, you talked about the Hawaiian islands being an island, I think that's very important because I think what we need to focus on is take that concept as we look for adding as much renewable onto the big grid, the island, if you will, as we possibly can. And depending upon what your substitute is and in the case of imported fossil fuels, it's a pretty high cost, as you know.

So we've had a program called Steel for Fuel where literally the steel is the renewables and what we're displacing is the fuel. And it turns out that the cost of the fuel that you save covers, and then some, the cost of the steel.

That's exactly what, I think, Hawaii is doing. And I think you'll find that you can have on that island or the big grid, if we were here in the Continental U.S., you'll probably be able to get to that

60 percent, maybe even more. But there does come a saturation point on the big grid.

Back to your question about reliability where we're going to need storage and we're going to need dispatchable resources, I believe. And perhaps they come from biofuels, perhaps they come from hydrogen, geothermal. There's a number of different things, and I think we need to be technology agnostic about it.

So my point is we'll put as much renewables as we can reliably and affordably do on the grid or the island, then you need to look for these other technologies and the research that will help us make those technologies viable, is the role, I think, the Federal Government plays.

Senator HIRONO. Well, not just in support for research though, but we need support for, you know, there are these new technologies being developed for storage, et cetera, but we are going to need some help in how to implement or to put in place these innovations and that is where, maybe, the Federal Government has a larger role to play in addition to supporting the research aspects.

Mr. FOWKE. I would agree with that. I also would agree that's where your utility can play a big role too. We do a very good job of starting small and then scaling up to speed of value.

Senator HIRONO. Yes. Thank you.

I do have further questions for the record that I will submit.

Thank you very much.

The CHAIRMAN. Thank you, Senator Hirono.

Senator King.

Senator KING. Thank you.

Mr. Fowke, just to follow up. Isn't storage and demand response dispatchable? I mean, you turn it on, it comes into the system. You seem to imply that it has to be a gas plant or something.

Mr. FOWKE. So I'd answer that yes and no and let me explain, if I could. There are things that the dispatchable resources do that bring attributes to grid health that you're not going to necessarily get from renewables. But the biggest issue——

Senator KING. I am not talking about renewables, I am talking about batteries and demand response.

Mr. FOWKE. That's correct and they——

Senator KING. Those are dispatchable.

Mr. FOWKE. They can play a role with that.

Senator KING. Okay.

Mr. FOWKE. The bigger aspect is if you think about a mountaintop, it's a lot easier to shave the peak off the mountain than it is as you work down that mountain. That first 4 hours, once you shave that peak, now you're looking at trying to get at 8 hours. And if you think of that mountain, it's flattened out and it's wider.

Senator KING. I understand.

Mr. FOWKE. And you start to need a lot more batteries and a lot more demand response and as you work down the mountain it just comes all the more——

Senator KING. I do understand that, but I just wanted to make the point that we are talking about a dispatchable resource.

Mr. FOWKE. Yes, frequency regulation, all the things that my colleagues talked about, that's where batteries can play a big role.

Senator KING. Mr. Crabtree, just for your information and the information of our friends that are here—I am working on a bill that involves a joint venture between the Department of Energy and Department of Defense.

Carrying fuel is a big risk for our troops. I think that there is a relationship, a joint venture, as I say, and also a bill that will discuss the issue of how to properly value those resources.

I am asking for your cooperation and assistance in the creation of that bill. If there are members here with a lot of knowledge in this audience, please be in touch with my office as we try to put this bill together. I look forward to your suggestions.

As I listen to this discussion, we talk about value and, Mr. Davidson, you talked about how pumped-storage and batteries are somewhat the same. They are high capital cost but low operating cost. And yet, as I have seen the development of energy pricing and markets and all of that, it favors low capital cost. I guess what I am getting at is, don't we need long-term contracts in order to help develop these capital-intensive applications?

Mr. DAVIDSON. Senator, yes, I think that's exactly what we do need or some other type of incentive that would encourage that large capital investment.

Senator KING. I used to be in the hydro business and if you could not have a 15-year contract, you could not have gotten financing.

Mr. DAVIDSON. Right.

Senator KING. Because you have a high capital cost that has to be amortized as opposed to just a day-to-day operating cost. Mr. Ott, is that correct?

Mr. OTT. Yes, well, that's the key. And I think one of the debates around the capacity market revenue for storage is it's the only long-term market we have.

So one other alternative to long-term contract is to have longer-term markets for these grid services like, you know, like we see on some of the exchanges for energy. So there's other alternatives.

Senator KING. But that is something that we have to be talking about because otherwise the financing drives everything toward, you know, low capital costs, toward natural gas plants that are cheap to build and can be moderately too expensive to operate.

Regulatory hurdles, interconnection delays and those kinds of things—talk to me, Mr. Ott, about what the regulatory issues are in getting these things permitted and online, and are there significant delays? Is that something we can help with?

Mr. OTT. Generally, I think, the volume, the volume of interconnections coming in with these distributed resources. Like I'd mentioned, we have, you know, a couple 100,000 of them.

I think the real key is for us to streamline, if you will, for the small stuff. We don't have to go through the same, you know, I'll say, engineering that we would for a bigger generator. And I think how streamlining, how we approach that and getting FERC to agree to that is probably a way to lower barriers even further than they are today.

So those kind of things——

Senator KING. So I understand interconnection on some of these can take more than a year, a lot of work.

Mr. Kumaraswamy, do you have thoughts on this regulatory side?

Mr. KUMARASWAMY. Yeah, no, I think that's a good point. I think I may have touched on the point briefly also.

If you think about energy storage, things are highly precise and controllable resources. So they're very different from a traditional gas-based generation resource.

And so, I think you have to think about it from that lens of how do you study the interconnection in a manner that's fast enough that can let this resource come online and start providing services in a matter of like six or eight months and not let the interconnection process be the choking point for a resource that can deployed in a matter of months. Right? And so, that's where, I think, there needs to be a little more thinking in terms of the process that you would adapt for, you know, a resource like that which is highly controllable.

Senator KING. Mr. Ott, you mentioned several times the importance of frequency regulation as an asset. Does that have a price? Does that have a value in the current market?

Mr. OTT. Absolutely. It has a tremendous value, that's why we've gotten the response from having 300 megawatts of batteries invested on market so it's completely competitive. So yes, it absolutely has high value.

Senator KING. So it is a capacity payment. There is a frequency, right?

Mr. OTT. Synchronized reserves, frequency capacity, so there's multiple revenue streams that these resources—the only one that has a forward component to it though is capacity which is why it's controversial. My point is, I think we can make some of these other markets have forward components that get more——

Senator KING. Well, my understanding is that some of the regional RTOs are talking about devaluing batteries to 70 percent versus 100 percent for other devaluing the capacity estimates. Have you encountered that?

Mr. OTT. That's for the long duration stuff.

Senator KING. Right.

Mr. OTT. But my point is, is that I think you can accentuate the value and frequency regulation of these other short-term services. So I think there's a counter balance there.

Senator KING. We have talked now mostly about grid-scale. I am way over time, I am sorry. But I would like to hear perhaps for the record about distributed storage, not grid-scale necessarily, but grid-scale in the aggregate, households, other kinds of distributed storage. I think that is an important part of this aspect, of this, that we haven't talked about.

Thank you, Madam Chair.

The CHAIRMAN. Thank you, Senator King.

Senator Barrasso.

Senator BARRASSO. Thank you, Madam Chairman. I thank you and thank the Ranking Member for holding this important hearing this morning.

While we are working to advance low-carbon technology through innovation in carbon capture technology systems, advancement in

energy storage in that arena is really important in terms of integrating the low-carbon sources on to the grid.

So we have discussed today one of the main challenges with integrating renewable energy sources into the grid is the intermittent nature of these sources. Baseload energy sources, coal, natural gas is going to continue to play an important role in providing low cost, reliable and onsite energy solutions into the future.

In February of this year the Committee held an important hearing on cybersecurity efforts in the energy industry. I know we are still in the process of researching and developing grid-scale energy storage technologies but, I think it is from the standpoint that one of the books on Bill Gates' recent reading list was called, "The Grid," about how it was formed and where we are today.

The question for any of the witnesses is, as we consider ways to improve security throughout the electricity grid, how are we planning to protect storage facilities?

Mr. OTT. So effectively, as you look at creating, I'll say, resilience, diversity, et cetera, really, it's through, not depending on one type of resource, or not depending on any one kind of technology. It's really promoting diversity, if you will. I think the real answer to resilience is to have more than, not all your eggs in one basket and have more alternatives. And I think that's really the same approach we take for storage.

Senator BARRASSO. Anyone else? Yes, sir, Doctor?

Dr. CRABTREE. If I could comment, I think it's a great question and picking up on what we just heard. Diversity is very important and flexibility. So if you add storage to the grid suddenly there's more than one or more than two or more than three ways to provide power in the event of an outage, be it a cybersecurity one or a weather outage. And that is a huge advantage.

So I would couple that with one more comment and that is decentralization is important. So when things are centralized then the central power plant goes out and the whole system goes out. When it's decentralized, through microgrids or on the distribution grid, it's much safer against every kind of outage. So I think this is one of the ways in which we can protect the storage.

Senator BARRASSO. And beyond the outage standpoint is the issue of the range that we are seeing in terms of energy needs. We have had a number of extreme weather events, major cold snaps, tornadoes, flooding, hurricanes, each presents specific challenges to electricity providers, to the grid infrastructure. It is foreseeable that a disaster could damage or eliminate an energy storage facility too, so baseload energy sources like coal, natural gas, to me are needed in this in every instance.

How can we continue to ensure that affordable, reliable, easily dispatched energy sources like coal and gas remain part of the electricity generation mix? Anyone? Yes, Mr. Ott?

Mr. OTT. Again, I think it's key to equitably value the contribution. We've had a debate about should we pay, you know, 15-minute battery capacity payments that are generally suited for nuclear plants, coal plants, gas plants. My answer is no. There's other kind of revenue streams that they fit better for.

So I think it's really just to make sure that from an infrastructure planning perspective, we recognize the value of these baseload assets and make sure we have the markets recognize those values.

Senator BARRASSO. Since you mention planning for the future, thousands more electric vehicles are expected to come online in the near future. We have seen the commercial during the Super Bowl from one of the car companies about what high percentage of their new sales will be of electric vehicles. To me, that is going to add a new major demand to the grid.

Recent studies showed electricity consumption in the United States could increase as much as 38 percent by the year 2050 as more and more electric vehicles hit the market. So, for anyone, do you believe we are going to be able to develop the energy storage technologies in time to meet this incredible electricity demand increase?

Mr. FOWKE. Senator, I think that's a really good question.

I think it's yes, you need to develop the infrastructure, but I think the requirements to develop that infrastructure can be minimized if we put in the right incentives through rate design to encourage off peak charging.

And that's something we're piloting at Xcel Energy, and it's working very nicely. And that requires state regulators to be more flexible than perhaps, you know, traditionally one-size-fits-all have said.

And I also would tell you that I'm proud to say the electric utility industry is not the number one carbon emitter in the United States anymore. It's transport. And the opportunities for EVs from an economic transition, I think, is really quite promising. In fact, if you charge up your car today it's a $1 equivalent of gasoline—so with a 70 percent carbon emission reduction. I think we've got some real opportunities there. The infrastructure, I think, can follow that.

Senator BARRASSO. Thank you.

Thank you, Madam Chairman.

The CHAIRMAN. Thank you, Senator Barrasso.

Senator Cortez Masto.

Senator CORTEZ MASTO. Thank you. Thank you very much, Madam Chair.

I do want to follow up on some of the conversation that Senator King and some of the others had that I have heard with respect to highlighting the role that distributed and residential storage has increasingly played, particularly as I see it in the State of Nevada as well.

I know that these technologies provide unique benefits that grid-scale cannot provide such as local reliability and resiliency. In fact, residential storage installation in the U.S. has increased more than 200 percent annually during the past four years.

I guess my question to the panel is, what are the challenges to implementing more expansive deployment of residential storage units, having them implemented at an individual residence, but also putting them to greater use within a greater network? I am curious about the conversation there. Then along with that conversation, what can we do as the Federal Government to also continue to support and incentivize residential storage?

Dr. CRABTREE. May I comment on that?

Senator CORTEZ MASTO. Please.

Dr. CRABTREE. I think it's a very good point that behind-the-meter storage or distribution grid storage has a huge role to play. I would say certainly at the residential level it's very important. It might be even more important at the neighborhood level.

So you could imagine an aggregator coming to a neighborhood of homes and saying I'll put a solar panel on every roof in this neighborhood. I'll pay for it. I'll buy a battery that's sized to the neighborhood. I'll pay for it. I will put in an energy management system that will direct all of that rooftop solar to the neighborhood at the time and place that it's needed. For example, I'll charge your electric vehicles at night and this will relieve demands on the grid. And I'll do it at a lower cost than you are now paying as a ratepayer, because we're producing that rooftop solar that we're using locally.

So, I think one of the, you said, what can we do? We can encourage that kind of innovation. At the moment that field is wide open and aggregators have not stepped in to take advantage of the opportunity, partly because, maybe, it's risky and partly because it hasn't been encouraged. So I think there are huge opportunities there.

Senator CORTEZ MASTO. Yes, and I would say it is on the drawing board. I have talked to some of our rural co-ops who are interested in doing just that.

I guess my question is what more can we do to incentivize it and ensure that it becomes more than just on the drawing board and they have the ability to actually put this into action?

Mr. KUMARASWAMY. I would say that one of the ways in which energy storage provides for some of these other benefits to the market typically doesn't value, right? There's a lot of benefits that storage brings to the table, including the resilience ones that was talked about previously and in many cases what we find is that either in a structured market, in a wholesale market structure or in a traditionally regulated structure. You can at least find it hard to value these types of benefits.

And so, one way of, you know, getting through that puzzle is to make sure that you have the Section 48 and 25D of the investment tax credit be applicable for standard owner energy storage devices, right? We think of it as an incentive to better recognize the value that storage provides that are not being captured in the wholesale markets or in some of the structured markets. That's one.

I think the second one, honestly, is that we are moving into a place where we have to be extremely prudent about incurring capital costs on single use assets, right? So any capital asset, whether it's a natural gas peaking plant or a large transmission distribution line, we have to be extremely prudent before we incur an expenditure and put the burden on ratepayers for the next 20, 30 years, right?

And so, I think that's where the collection of whether it's grid-scale storage or the combination of resources which include demand response or behind-the-meter storage, all of them come into play where you look at a portfolio of these solutions that can potentially take away the need for you to incur large amount of capital ex-

penditures that are fractionally utilized for a significantly long period of time. That's what we want to avoid.

Senator CORTEZ MASTO. Anyone else?

Mr. FOWKE. I think all of that is valid but I will have to take, Senator, a little bit of a contrast. Scale really matters in our business, and so I would say that the underlying technologies just need to come down in price so at some point, you know, the delta between large and small isn't as pronounced as it is.

And of course, the debate about some regulatory policies that were put into place to encourage that nascent technology need to be revisited and that's not without controversy. But what we need to do, what I am trying to do as the CEO of a large utility, is achieve that 100 percent carbon-free goal, keep my prices affordable for everyone and reliable.

So I'm very much focused on avoiding cost shifts because that tends to cloud the economic signal that, I think, we all need to be looking at to achieve that goal. And so, as we advance the technologies, as they make this more possible, we do have to be willing to go back and revisit older policies that were good at their time but maybe have lived past their prime.

Senator CORTEZ MASTO. Thank you.

I noticed my time is up.

The only other question, and I will submit it for the record, is the workforce. What is the workforce that we need for the discussion that we had here today? And I will submit that for the record.

Thank you.

The CHAIRMAN. Thank you, Senator.

Well, Senator, I will make it easier for you. I will ask that question because that is something that I, too, am curious about where when I just came from a speech earlier this morning about the future of nuclear and you cannot talk about the future of nuclear in this country unless you talk about a skilled workforce. Is this an area where we need to be doing more to be able to address the growing demand? Doctor?

Dr. CRABTREE. May I comment?

Great point and I think when you look at the workforce and you look at what's happening to the grid, everything we do about electricity and the electricity grid is domestic. So when we talk about a 30 percent increase in demand from EVs, those are domestic jobs and domestic infrastructure that we need to build.

So training that workforce, I think, is critical. There will be some dislocations from technologies that, let's say, are no longer as relevant as they used to be. We can make up for those, some of those, dislocations by retraining or training the next generation to do what's needed. I believe that it's a huge opportunity that we should embrace.

The CHAIRMAN. Good.

Let me ask you, Mr. Fowke, a question about your goals here, 80 percent carbon-free in your service territory by 2030, 100 percent by 2050. You have not really outlined what Xcel is doing, specifically which technologies you are moving to.

Is it a fair statement to say that you could not achieve these ambitious goals, recognizing we don't have federal mandate out there,

but as a business decision, you could not achieve these goals without greater application of energy storage?

Mr. FOWKE. I think that's a fair statement. It really will depend on what other technologies, Senator, become economically viable.

I know that if we don't make it affordable and if we sacrifice reliability, the clean energy transition is going to take a major setback.

So today with the prices I've seen over, just the last 10 years, really the last 3 years, in wind and solar, I can do this with economics in mind. I have to have reliability.

So whether that is today, the implementation of storage as much as we can until we start to go down that cost curve that I mentioned or peaking gas generation, that, the economics is what I'm after. And again, I know how to get to that 80 percent, the next 20 percent is going to take some of these other technologies, advances and long duration storage.

And again, I think, dispatchable generation, and we talked about many of the different ways that could be—hydrogen, carbon capture, next generation nuclear.

The CHAIRMAN. One last question for me, and then I will turn to Senator King and Cortez Masto, if they have more.

But in their budget request for this fiscal year, DOE has proposed the Advanced Energy Storage Initiative. This is a $158 million cross-cutting program that establishes goals for cost competitive energy storage. Your free advice here on how and where the Department should focus its research and development efforts as they are looking to reduce the cost of energy storage technologies. What would you have them do? Dr. Crabtree?

Dr. CRABTREE. Yeah, thank you, that's a great question.

I believe that up until this point the way we've treated storage and to a certain extent, the grid, is a little bit too piecemeal that one needs to look strategically and holistically at the whole system and look for the next 20 or 30 years which is how long it will take to make this transition to a fully modern grid, that we ought to deliberately take steps that will produce the outcomes that we wish to have rather than letting the market give us what, you know, what it would produce by itself.

So I think we need, sort of, an energy storage and grid ecosystem to look at. This DOE proposal is one step along that route but we ought to have a very serious look at strategically where are we going and how are we going to get there.

The CHAIRMAN. Any other advice?

Mr. Kumaraswamy.

Mr. KUMARASWAMY. Sure, that's a great question also.

I think I noted in my testimony that the National Renewable Energy Labs have been a significant source of research on studying the capacity value that energy storage brings and, quite honestly, they have, given the body of literature that we need for us to be successful in many of the efforts that we need across the regional power markets.

And so I think I would say that that's one area that needs to continue in terms of making sure that we better get a handle on what is the amount of duration of storage that we need to capture the full capacity value? Is it four hours? Is it six hours? Is it eight

hours or is it ten hours, right? And so, what fraction of duration would you need to capture what percentage of capacity value?

And that research needs to continue, and then the second one that we are still gaining very nascent stages of exploration is this use of energy storage for solving some of the transmission needs that we have on the grid side, right? So how can you use these fast-acting energy storage devices to provide for solving congestion issues on the transmission system, right? How can we better utilize the existing transmission system that we already have in a more efficient manner? Are there ways to think about those applications of storage? Those are key areas that would significantly benefit by, you know, research by the national labs.

The CHAIRMAN. Very good, thank you.

Senator King.

Senator KING. Thank you.

I think one of the clearest learnings we have had this morning is the importance of research and the importance of the role of the Federal Government in conducting that research.

And again, I think you know, I think of George Mitchell and fracking and the importance of revolutionary change and that was supported, in some significant measure, by Department of Energy research. That changed the world, and I think this is another area.

Again, I think, Madam Chair, this is a place where there could be a profitable combination between the Defense Department and the Department of Energy because of the important role that this plays with them.

Mr. Crabtree, you mentioned something in passing that I think deserves emphasis. Rate design and the use of storage for battery-powered automobiles to absorb excess capacity, energy and grid capacity, in the nighttime.

The grid, I have often characterized, is like a church that is built for Christmas morning and there are a lot of empty pews in February and March, because it is literally designed for the hottest, most heavily used day of the year and it has to be in order to be reliable.

But that means there is enormous excess delivery capacity, usually at night, particularly in the winter. And so, to the extent we could use rate design to encourage charging of automobiles or to go further, to encourage things like electrothermal storage, heating your water at night. I mean, there are a lot of uses like that, I think. I am old enough to remember when we looked at our watch when it became nine o'clock because the telephone call was cheaper.

[Laughter.]

People do change behaviors because of price signals. And right now there is really not a price signal, and yet there ought to be and it would lead to a more efficient utilization of the grid without an increase of the capital cost, no new wires or poles which would lower the cost of distribution and transmission for everyone because of more kilowatt-hours divided by the same capital cost.

So I think that is a very important point. That is essentially a state level decision. But time-of-day pricing, I think, is a very important part of this solution.

Finally, Mr. Fowke, I admire your commitment to where you are going, to where you are taking your company and it is a very important step for the country.

On the issue of shifting when we have household solar and batteries, I think the important question there is we have to be very precise about the value of what you are getting versus what it is costing. In other words, it is not a dead loss. There are values to the utilities. There is a national security value in terms of the distribution of the grid so that if one plant or one transmission center goes down, the whole grid does not go down. There are carbon avoidance values, resiliency, peak shaving, all of those things.

So I understand, but I just want to be sure the equation is on both sides, that the value question is not just what is the cost and are we loading these costs on to other consumers, but what are also the benefits?

And that, I think, that is an important part of this consideration because there are places in the country where utilities have placed, I think, exorbitant penalties to discourage the development of distributed energy that are really unjustified by the true cost equation.

I think this is so incredibly important, and I commend the panel and the Chair. This has been a very important hearing, and I look forward to continuing the discussion.

To the extent any of you have follow-up thoughts, I hope you will submit them to the Committee for our consideration. But thank you all for the work that you are doing.

Mr. Davidson, thank you for the work you do in Maine. I think you have 600 or 700 megawatts of hydropower in Maine. It is an important part of our energy resource, and I appreciate your company's engagement with businesses and entities in our state.

Thank you, Madam Chair.

The CHAIRMAN. Thank you, Senator.

Senator Cortez Masto, any final thoughts?

Senator CORTEZ MASTO. So one area that dovetails—and we have had hearings on this previously—with this conversation and any conversation we have when we are expanding access and interconnectivity to the grid is cybersecurity. To me, that should be incorporated into all of the discussions we have, particularly as we build out the new architecture and we are looking at incorporating new technologies.

I do not know if anybody has a comment because that could be a whole other hearing, but to me, that should always be a consideration and always be a topic of the conversation when we are continuing to figure out our role here at a national level and a local level with respect to the grid.

The CHAIRMAN. Clearly a subject that is always on our mind as we look at any of these energy matters.

We appreciate the really good discussion I think that we have had this morning. The efforts that you all bring from different perspectives here, I think, helps round out the conversation in a way that is very helpful to us. So we thank you for that.

We know that we have a lot more work to be done in this space, but we recognize that it plays a very key role in how our energy future, our energy portfolio, really moves forward.

We thank you for your contribution, know that you will be hearing from us, whether it is additional questions from members here on the panel or on follow-on as we look to develop legislation.

With that, I thank you very much, and the Committee stands adjourned.

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

# APPENDIX MATERIAL SUBMITTED

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Dr. George Crabtree**

These responses have benefitted from comments by Sue Babinec, Linda Gaines, Jeffrey Spangenberger, Venkat Srinivasan, Mark Petri, Don Hillebrand, Cynthia Jenks, and Greg Krumdick, Argonne National Laboratory.

**Questions from Chairman Lisa Murkowski**

**Question 1:** *When it comes to energy storage, our growing dependence on China and other countries for all needed battery materials is a glaring strategic national security vulnerability. Additionally, the U.S. is ceding this emerging industry to Asia and making deployment less certain. In order to see continued growth in energy storage, what is needed in terms of raw materials and battery manufacturing? Are you examining these supply chain issues? How can we ensure some parts of the supply chain are done domestically?*

*Global energy storage leadership*
The U.S. is well behind China in battery manufacturing and in securing its supply chain for lithium-ion battery materials. China now accounts for 60% of lithium-ion battery manufacturing, compared to only 13% for the U.S. Also, China has strategically and deliberately secured its supply chains for battery materials like lithium and cobalt by buying foreign mines and signing long-term contracts with foreign suppliers. In the next two decades, the dramatic growth expected for electric vehicle deployment, as well as the continued trends in the electrification of military platforms, makes battery manufacturing and supply chains a critical issue for U.S. economic prosperity, job growth, and national security.

A whole-of-nation approach is clearly warranted to drive U.S. energy storage innovation while also building U.S. industry's domestic sourcing capabilities as commercial and military applications will continue to gain in strategic importance. To address these shared challenges, the U.S. government must bring together strategic and non-traditional industry partners with the U.S. national lab system, NASA research centers, and defense lab enterprise through new programs to lead global energy storage innovation and catalyze the U.S. battery manufacturing sector. Historically, the U.S. has created the critical technologies but ceded its manufacturing capabilities offshore. In addition, the U.S. must take a leadership role in the recycling of key battery materials to secure future U.S. supply chains.

*Vibrant, stable long-term climate for battery development*
A vibrant and stable long-term climate for battery development and application is central to creating a competitive enterprise for lithium-ion battery manufacturing in the U.S. (Mai 2019). Energy storage is critical to a host of innovative and profitable business plans for the future in electric vehicles as well as in charging stations for them; in electricity generation, transmission, and distribution; in electric flight; and in energy management. Batteries are like computers – ubiquitous tools so essential for so many applications that they become a foundation of innovation for the economy, industry, the military, and society. The federal government should take a whole-of-nation approach to promote the growth of energy storage with actions that establish a stable, long-term, vibrant market for energy storage technologies in the U.S. These actions can include, for example, support for electric vehicle sales; for resilience and reliability improvement and renewable integration on the electricity grid; for electric air taxis and electric regional flight passenger service; and for energy management across the board to increase efficiency and

reduce waste. Batteries and other forms of energy storage are central to all of these outcomes; establishing long-term support promoting their growth would attract private-sector innovation and investment in energy storage and the profitable business platforms they enable.

*Battery manufacturing*
Battery manufacturing in the U.S. is decidedly second class: China's share of global lithium-ion battery manufacturing is now 60% and growing; the U.S. share is 13% and stagnant (Mai 2019). Strong steps must be taken to change this trajectory. In addition to stable policies promoting long-term growth in energy storage and the industries it serves, the U.S. can take positive steps to promote battery manufacturing and secure the supply chain for battery materials (Ma 2018). The U.S. already has a robust auto manufacturing sector, a strong foundation for building an electric-vehicle manufacturing footprint, and a significant battery manufacturing footprint in Tesla's Gigafactory and other much smaller projects. Much greater progress is needed and can be promoted at the federal level. (Ball 2019) The opportunity includes not only electric vehicles, the opportunity at hand, but also the longer range opportunities for storage in the electricity grid and in electric flight, which will build on the technologies and experience gained in the electric vehicle market. Emerging opportunities in the grid include converting variable renewables to dispatchable power, replacing gas peaker plants with batteries at lower cost and higher performance (Denholm 2019), and increasing the resilience and reliability of the grid against extreme weather and foreign cyber-attacks. In electric flight, opportunities include commuter air taxis, package delivery, and regional passenger flight.

Growth of these U.S. industries requires not only nurturing domestic battery manufacturing, but also securing critical non-U.S. supply chains that are the life blood of battery manufacturing. Strong steps are needed at the federal level to build a U.S.-based battery manufacturing presence.

*Recycling as a supply chain*
In the short term, supply chains for domestic battery manufacturing can be secured by establishing new contracts with domestic and foreign suppliers. In the longer term, lithium-ion battery recycling can be strongly promoted. Recycling can play a significant role in battery manufacturing, reducing the cost by as much as 20% and supplying up to 50% of the raw materials (Mayyas 2018). The U.S. has a limited capacity for raw material production. Exploiting recycled batteries for their raw materials is a powerful alternative to buying them from foreign suppliers. Promoting a domestic recycling enterprise for end-of-life battery materials, especially those from foreign sources, provides a ripe opportunity to reduce our dependence on foreign supply chains.

There are other innovative and attractive recycling possibilities: for example, re-use of automotive-propulsion batteries with reduced capacity for use as stationary energy storage in the grid and feeding of excess power back to the grid during electric vehicle use. Plug-in hybrid bucket trucks have already been used to supply emergency power to hospitals.

The most economically attractive recycling opportunities are in direct recycling, where battery components such as cathodes and anodes are removed intact from used batteries, refurbished without reducing them to their lower value metal-salt constituents, and replaced in new batteries. Design to

recycle, or rejuvenate, is another promising and untapped direction, where batteries are designed from the beginning for easy de-manufacturing and materials recovery, or for extended use applications. Direct recycling and design to recycle are still in their infancy. They are untapped opportunities for the U.S. to pioneer and to own as essential future technologies. Significant funding should be appropriated to these recycling directions while they are still relatively undeveloped by others.

*Leadership in next generation batteries*
Finally, there are enormous needs for next generation batteries in which cost and performance significantly exceed today's state of the art. Lithium metal or silicon-based anodes could replace the graphite anodes of today's lithium-ion battery to double the energy density for a 500-mile electric vehicle range and make possible long-haul electric freight trucks, electric air taxis, and regional electric passenger flight. Solid-state electrolytes could eliminate thermal runaway, the primary safety hazard of lithium-ion batteries. New cathode formulations could eliminate cobalt, the most expensive and highest supply-risk element of lithium-ion batteries. Lithium-air and lithium-sulfur batteries promise two or three times the energy density of today's lithium-ion batteries at lower cost, enabling a host of applications in transportation, the electricity grid, electric flight, and the military. These prime areas of battery research and development should be funded at a significantly higher level. The Vehicle Technologies Office in the Office of Energy Efficiency & Renewable Energy (EERE) has had a sustained effort in the topics listed above, including, recently, in the area of recycling of spent batteries. Vehicle Technologies, along with the Advanced Manufacturing Office in EERE, the Department of Energy's Office of Basic Energy Sciences, and the Office of Electricity have been at the forefront of funding battery research aimed at maintaining U.S. leadership, as also has the National Science Foundation.

This advanced battery technology will move off-shore, as it has in the last 10-15 years, unless strong steps are taken to stop that from happening. There needs to be a more aggressive approach to keeping next-generation U.S.-developed technology in the U.S. Examples of this include incentives for all U.S.-funded inventions to manufacture in the U.S., a broad geographic buildout of piloting facilities so that entrepreneurs do not have to travel long distances to scale up new technology, reduction of cost-share requirements to enable financial flexibility for startups, and financial incentives for strategic investors to build production facilities in the U.S. Without that approach, all our R&D efforts will not generate U.S. economic gains.

**Question 2:** *Different types of energy storage technologies are generally suited for particular applications. For applications other than frequency regulation, what energy storage technologies are most promising, and where are they in development?*

The most promising energy storage types are battery electrochemical energy storage, thermal storage, pumped hydro storage, and compressed air storage.

*Electrochemical energy storage*
Batteries are a versatile and widely deployed form of energy storage, including non-rechargeable and rechargeable types for personal electronics, car-starting (usually lead-acid) batteries, nickel-metal hydride

and nickel-cadmium batteries originally used in hybrid vehicles, and the lithium-ion battery introduced by Sony in 1991.

*Lithium-ion batteries* have been remarkable performers, raising their energy density and lowering their cost every year since their introduction. They are the highest energy density rechargeable battery on the market and have enabled the personal electronics revolution for smart phones, laptops, tablets, watches, and clothing, and are now finding uses in electric vehicles, the electricity grid, and electric flight. For transportation and the grid, Li-ion batteries face challenges in cost, energy density, charging time, lifetime, and safety, performance requirements that are much more stringent for vehicles and the grid than for personal electronics. Electric vehicles with lithium-ion batteries are not yet at cost parity with gasoline cars, but are expected to reach that point by the mid-2020s as battery prices continue to fall. Reaching cost parity with gasoline vehicles will be a milestone for electric vehicles and will significantly accelerate their deployment.

For the grid, a major turning point occurred when Li-ion batteries were coupled with solar panels to produce electricity in sunny Arizona and Nevada for less than 3c/kWh, and in Los Angeles for less than 2c/kWh, a lower cost than every other generation technology (McMahon 2019). Lithium-ion batteries are competitive with gas peaker plants in some instances, and will become the favored economic choice for new construction of peaker plants by the mid-2020s (Sioshansi 2019). Other uses on the grid include managing two-way electricity flow from rooftop solar in the distribution grid, reducing utility demand charges, and providing high-quality digital power. In electric flight, lithium-ion batteries can power drones for surveillance and package delivery, and could one day propel air taxis and short-haul passenger flight.

Lithium-ion batteries reach cost and performance limitations, however, for high energy density applications such as long-haul freight trucks, passenger flight and many military applications, such as months-long independence of domestic and foreign bases from the local grid, lightweight soldier power, and high energy weaponry. These applications require cheaper, higher energy density batteries such as Li-sulfur and Li-oxygen or Li-air, or other next generation batteries with Li-metal anode or solid-state electrolytes.

In *flow batteries* the solid anode and cathode are replaced by liquid stored in a tank, a fundamentally different battery architecture. In flow batteries energy storage capacity scales with tank size, an attractive feature for the large capacities needed for the grid: for example, to back up a wind or solar farm on overcast or calm days. Li-ion batteries are not economically suitable for more than an approximately four-hour discharge. A second advantage of flow batteries is the independence of energy density and power density, allowing the battery to be tailored for specific applications. For example, they could possibly find application in backing up a wind or solar farm (high energy density) or fast charging of several electric vehicles at once (high power density). A third advantage is long lifetime, because there is no strain in the liquid electrodes on charging and discharging, eliminating the fracturing that limits the life of solid electrodes in Li-ion batteries. Flow batteries are now in a rapid state of development, dramatically expanding the materials diversity and performance quality that can be achieved.

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Dr. George Crabtree**

The U.S. is delinquent in the global energy storage race to develop and retain manufacturing capabilities for *next generation batteries* (advanced Li-ion and beyond Li-ion), a race spurred by the many compelling storage applications in personal electronics, electric vehicles, the electricity grid, electric flight, and energy management. Although lithium-ion batteries were developed in the United States and Europe, the manufacturing leadership and accompanying economic growth for Li-ion batteries have been lost to Japan, South Korea, and primarily China. However, next generation batteries are being developed on a level playing field, with no country or region having a historical advantage. This enables innovations made at home to be kept at home with the accompanying economic and job growth. With so many important applications and so many promising battery storage technologies, this is a clear opportunity for the U.S. to regain a leading position in the energy storage sector. Since the world-class suppliers of batteries are not in the U.S. and any new technology would naturally migrate to them, we must take relatively aggressive steps to ensure any pilot and first plants are situated in the U.S.

*Thermal storage*
Thermal storage (Spector 2017) captures heat from combustion, concentrated sunlight, or the earth, and preserves it at its capture temperature for hours, days, weeks, or months. The efficiency of thermal storage depends on the degree of thermal insulation surrounding the storage chamber, and the energy can be held for as long as months without serious loss. Thermal energy storage is especially useful where there are natural temperature swings, for example, hot days and cold nights (as in the desert) or warm summers and cold winters (as in northern latitudes). It is most useful when heat is the final product, as in building heating and air conditioning or in food refrigeration. In these applications it is a mature technology and has few remaining R&D challenges, though there are many engineering challenges to develop new applications. Thermal energy storage is also being proposed where electricity is the final product, converting excess electricity at night to heat, and re-converting the heat to electricity when daytime demand is high. These applications use reversible heat pumps for the conversion in both directions and are still in the exploratory stage.

*Pumped hydro storage*
Pumped hydro works on the simple principle of using excess electricity to pump water uphill and recovering the electricity by letting the water run downhill through a turbine. This is a very mature technology, first deployed in Italy and Switzerland in the 1890s; there are few remaining R&D challenges. Pumped hydro achieves round-trip efficiencies of 70%-80% and is the most widely deployed energy storage technology on the electricity grid, making up 95% of utility scale storage. Most pumped hydro was installed in the 1960s, 1970s, and 1980s, when the best geographic sites were developed. A variation of pumped hydro uses any heavy material, such as rock or concrete, in place of water and lifts and lowers the material to store or release energy.

*Compressed-air energy storage*
Compressed air (Donev 2018) is very much like pumped hydro, except that it compresses and releases air as the storage medium. There are three operating compressed air energy storage systems in the world: a 110 MW plant in McIntosh, Alabama, commissioned in 1991; a 290 MW plant in Huntorf, Germany, built in 1978; and a 500 MW facility in Gaines Texas, launched in 2012. Compressed-air energy storage uses mature technologies such as pumps and turbines, and there are few remaining R&D challenges. The

engineering challenge is lowering the cost and proving the viability of the system in various working demonstration projects.

**Question 3:** *Seasonal storage is sometimes viewed as the "holy grail" of energy storage, allowing the bulk storage of energy over long periods of time. Do you think that seasonal storage is achievable? What are the best candidate technologies for this application, what is the necessary cost-point to achieve this use-case, and are there programs at the Department of Energy working to develop these technologies?*

Seasonal energy storage is certainly achievable by many potential routes, including battery electrochemical energy storage, pumped hydro, thermal energy, and hydrogen. Seasonal energy storage addresses a seasonal variation in either the supply of energy or the demand for energy. The seasonal demand for energy is driven by heating in winter and air conditioning in summer, measured by heating degree-days and cooling degree-days. The difference can be as much as 85% in the upper Midwest (EIA 2018a).

Seasonal variations in the supply of energy will become more important as the grid becomes greener. As the fraction of renewable energy on the grid grows, more seasonal storage is required to bridge the greater seasonal variation in wind and solar availability compared to fossil generation. The availability of solar energy is measured by the length of the day. In Chicago, for example, winter gets 40% less sunlight than summer, not counting variation due to clouds. Wind shows similar strong seasonal variations dependent on local weather patterns, with variations as much as 75% in California and the Midwest (EIA 2019).

*Electrochemical energy storage*
Batteries with solid electrodes are relatively expensive compared to pumped hydro and thermal energy storage because they require two chemical conversions, from electrical energy to chemical energy and back to electrical energy. The practical discharge time of lithium-ion batteries is approximately 4 hours, too short for the long duration charge and discharge times of seasonal storage. Flow batteries are much more suitable, with large tanks of liquid electrodes that can store the large amounts of energy needed for seasonal storage. Still, the cost of flow batteries based on vanadium, the most prevalent flow battery commercially available today that could be applicable to seasonal storage, is too high for widespread deployment. Replacing vanadium with an organic molecule or with a cheaper inorganic material is a way to lower the price and raise the performance of flow batteries and is getting serious attention in the research community.

To achieve the "holy grail" of seasonal electrochemical energy storage for the civilian grid as well as U.S. military installations, the U.S. government could bring together the Departments of Energy and Defense to establish a new program (see response below to question 1 of Senator King). There is little doubt that the required battery materials and molecules exist or can be designed to usher in a new era of energy resilience with flow batteries.

*Long-duration energy storage*
In addition to seasonal storage, there are many applications for long-duration energy storage, often defined as greater than 10 hours. One example is batteries for backing up wind and solar farms, which

invariably experience at least two consecutive calm or overcast days per month and fairly often five or more such days in a row. The cost of providing 48 hours of electricity to back up wind and solar generation from lithium-ion batteries would be prohibitive. Flow batteries purpose-designed from inexpensive materials can serve this and other long duration needs. The Joint Center for Energy Storage Research, led by Argonne National Laboratory and funded by the DOE Office of Basic Energy Sciences, has developed such a battery and spun out a startup company, Form Energy, seeking to commercialize it. DOE is pursuing both seasonal and long-duration energy storage through the DAYS (Duration Addition to electricitY Storage) program funded by ARPA-E, the Advanced Research Projects Agency - Energy.

*Pumped hydro storage*
For *pumped hydro*, water is pumped uphill with excess solar electricity in summer, and allowed to fall downhill to produce electricity in winter. Though not yet used for seasonal energy storage, pumped hydro is a widely deployed, mature storage technology, geographically limited by the availability of water and local elevation differences.

*Thermal energy storage*
In seasonal thermal storage, solar heat is stored directly in a dense material such as concrete or rocks surrounded by highly insulating material to prevent the heat leaking out. Thermal storage is inexpensive and can hold heat with little loss for days, weeks, or months. Often the earth is used as a convenient insulating material in underground thermal energy storage. If summer solar heat is the input for seasonal thermal energy storage, there are no greenhouse gas emissions. The technology is still emerging, with three prime examples in North America: Richard Stockton College, the Veteran Administration Hospitals in Chillicothe and Columbus, OH, and the Drake Landing Solar Community, Alberta, Canada. The technology, though well understood in principle, is not widely deployed and has not been evaluated for many particular cases.

*Hydrogen storage*
For hydrogen seasonal energy storage, excess summer solar electricity is used for electrolysis of water, producing hydrogen and oxygen. The hydrogen is stored for combustion in winter to produce heat. There are no greenhouse gas emissions from hydrogen as a seasonal energy storage medium if the hydrogen is produced renewably from solar electricity and water—if burned to produce heat, the only product is water, not carbon dioxide. In contrast, the non-renewable production of hydrogen from steam reforming of natural gas produces as much carbon dioxide as burning the natural gas directly. Hydrogen energy storage is more expensive than thermal energy storage, because the hydrogen must be produced from electricity and water. Instead of burning the stored hydrogen for heat, it can be converted to electricity in a fuel cell to create an electricity-to-electricity seasonal storage system. This adds another relatively expensive conversion, from stored hydrogen to electricity, and is not at present economical compared to thermal energy storage.

*Cost-point considerations*
The cost point for successful seasonal or long-duration energy storage is determined by the cost of alternative technologies to provide the same service. There is no established technology for seasonal storage at present, so cost comparisons among the candidates are somewhat artificial. One can compare

the cost of seasonal storage candidates with the cost of simply producing the required energy when needed, the traditional historical practice. The cost of solar and wind, the emerging dominant generation technologies, are an appropriate cost-point comparison for candidate seasonal storage technologies.

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**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Dr. George Crabtree**

**Question from Senator Mazie K. Hirono**

**Question:** *The hearing was focused on grid-scale energy storage, but Hawaii is home to over 80,000 rooftop solar systems, and many homeowners and business owners in Hawaii are likely to include battery storage with their new solar panels. What new battery storage technologies could people see in the next decade that they could add to their homes or businesses, and what price and performance characteristics would you forecast for those technologies?*

The market for home energy storage is dominated by lithium-ion batteries whose price is falling significantly, now in the range of $400-$800/kWh for a home system ($250/kWh for larger systems). Advances in lithium-ion battery technology (such as silicon-rich anodes, pure lithium metal anodes, and solid-state electrolytes) are now in the laboratory or early scaleup phase and are likely to be at least five or more years from commercial availability. It is too early to predict the cost of such advanced batteries should they reach the commercial stage, but they could in principle be equal to or lower than today's commercial lithium-ion technology. Also promising for this application are flow batteries using inexpensive materials, which could, in principle, break the $400-$800/kWh price point, though no current design is far enough along in development to forecast commercial prices.

**Questions from Senator Angus S. King. Jr.**

**Question 1:** *Energy storage can play an important role on our military bases and facilities in terms of national security and resilience. DoD already has some compelling R&D underway on energy storage initiatives, but where are other opportunities for defense to play a helpful role in the research and commercialization of long-term energy storage resources?*

The Department of Defense (DOD) and Department of Energy (DOE) have different yet complementary approaches to energy storage innovation because they have different needs in many cases. In general terms, DOD investments are more concentrated on late stage research, development, and trial deployment for high energy density storage, whereas DOE investments are focused on basic energy sciences or early stage research and demonstration of high energy for transportation and low cost for grid applications. The promise of DOD-DOE research collaboration and opportunities was well highlighted in a recent report (Robyn 2019). In many cases, cooperation between DOD and DOE can be extended to NASA, which has special battery needs for electric flight and long duration space missions that strongly complement those of DOD and DOE. At the early stage of development, military and civilian research needs overlap strongly, while at later stages of development they will diverge. Even in the later stages, advances on the military side can migrate to the civilian side and vice versa to accelerate progress on both sides (Robyn 2019).

There are many ways that DOD programs, working in cooperation with DOE and NASA programs, can contribute to the research and commercialization of a world-leading U.S. energy storage presence. In particular, two new programs of record warrant immediate interagency collaboration:

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Dr. George Crabtree**

1. *Long-duration energy storage*: Long-duration battery prototypes are needed for greater resilience of the electricity supply for civilian and military base grids. Military bases at home and abroad require long-term independence from the local electricity grid to ensure the reliability of a needed military response in case of an electricity outage. There is a similar need on the civilian side to ensure reliability against extreme weather events and cyber-attacks that can cause crippling economic challenges for days or weeks.

   In addition, with a unified approach spanning all military applications, DOD can devise a program for re-using battery packs that have served their useful life in electrified transportation to a second useful life in grid storage, since DOD controls the physical assets in both cases, and it has a closed loop for controlling the transition. This would serve as a model and incentive for a similar program on the civilian side. By coupling this model to data accumulation and analysis by machine learning/artificial intelligence to determine the most advantageous moment to move a particular battery from transportation to the grid, DOD will gain maximum benefit from the battery re-use.

2. *Beyond lithium-ion batteries:* This is an untapped opportunity for both military and civilian needs for long-range and heavy-duty electric vehicles, mobile platforms, and electric flight and space applications. The last decade, especially the last five years, has seen significant advances in lithium-metal anodes, solid-state electrolytes, and conversion cathodes based on sulfur and oxygen. These advances have clarified and quantified many of the fundamental materials and phenomena challenges that must be overcome to reach application viability. Advances in tools for battery R&D have also been made in the last five years, including high brightness x-ray sources, high resolution scanning electrochemical probes, *in situ* and *operando* measurements of battery function, computational materials genome simulations of battery materials, and coordinated simulation and characterization studies of battery operation. At the moment, the U.S. leads in computational materials genome modeling of battery materials, a key advantage for shortening the development time and lowering the risk of technical failure for next generation batteries. This computational advantage, and the advantages we hold in sophisticated x-ray sources, high resolution electrochemical scanning probes, and other characterization tools, will soon be diluted as others learn from our experience.

The two programs should be a part of a whole-of-nation effort to catalyze a leadership position for U.S. battery manufacturing and applications. Such a leadership position for U.S. battery manufacturing also requires leadership in battery recycling, supply chains, and artificial intelligence/machine learning capabilities, as well as a clear U.S. definition of "energy resilience" for critical infrastructure and key resources:

*Recycling.* DOD could play an important role in the recycling of batteries. At present, DOD apparently does not recycle its batteries but uses third party recyclers, of which there are none in the U.S. that perform complete recycling. The DOD should support R&D for U.S. recycling and ultimately should use U.S. recycling facilities and workers. Furthermore, many spent batteries

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Dr. George Crabtree**

within the DOD infrastructure are stored for long periods of time, which compromises safety. Batteries should be recycled as soon as possible with minimal lag.

*Battery cell supply chains:* Presently, a large fraction of battery cells for deployment comes from Asia since cost is critical in the DOD analysis, and Asia has the lowest cost for large scale manufacture. The military could set forth a future requirement that all DOD batteries must be manufactured in the U.S. The military demand is large enough now to provide for volume pricing – but this will not happen unless the military makes a unified requirement across the services. Such a requirement would definitely be a great boost to the formation of a mass civilian market in the U.S. for battery cells.

*Machine learning and artificial intelligence*: These advanced computing technologies can be used in DOD/DOE research programs for dramatically accelerating materials discovery and for optimizing designs of complex interacting microgrids on both the military and civilian fronts and for creating energy storage devices with greater durability and, therefore, lower cost. This approach requires large data sets; there is an opportunity for it to thrive in an environment that nurtures approaches to sharing of data towards the common goal of improved design and operation.

*A uniform definition of resilience*: If the technical community better understood the meaning of resilience, including design parameters and functional constraints, they could better devise solutions. At present, there are too many definitions of resilience, and this inhibits progress.

In particular, programs on long-duration and beyond lithium-ion batteries, if properly resourced for the military and civilian efforts could solve the underlying materials challenges and integrate new solutions into prototypes suitable for rapid testing and commercialization or military deployment. This deliberate whole-of-nation approach could usher in a new era of energy resilience for the grid and military installations as well as new electric vehicle applications, including electric flight. Significant progress could be achieved in five years, with the initial emphasis on applying state-of-the-art experiment and theory to understand and solve the materials and phenomena challenges and the final emphasis on developing high performance prototypes. Moreover, for DOD/DOE programs the potential for interoperability between vehicle/mobile platforms and grid power/military-base applications holds further promise to generate energy-resilient capabilities through distributed storage and vehicle-to-grid architectures.

Collectively, long-duration and beyond lithium-ion battery programs would bear further strategic and geopolitical fruit for securing the nation's energy independence—and that of our international partners and allies—should the U.S. become the first nation to break the existing energy storage constraints on economic prosperity and global security. Electricity remains the only commodity for which instantaneous supply (generation) must be matched with instantaneous demand (load). China aims to own this space as part of "Made in China 2025," while some of our closest allies and partners have significant energy dependencies on Russia's commodity-based economy, which primarily fuels Russia's defense spending. The U.S. must achieve these advantages before our competition. The U.S. national laboratory system,

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Dr. George Crabtree**

defense laboratory enterprise, NASA research centers, and strategic industry partners now have the knowledge base equal to the task. The opportunity for a decisive leap forward in commercial and military energy storage capabilities is now. In addition to establishing new fully resourced programs for DOE-DOD-NASA collaboration to develop next-generation energy storage prototypes, Congress could also launch a National Research Council Study to identify impediments to and opportunities for greater DOE-DOD-NASA collaboration on energy research, development, and deployment.

**Question 2:** *What types of supports can the government provide to encourage greater implementation of distributed and residential behind-the-meter storage on a larger scale? How can rate designs be used to create price signals that encourage off peak charging for electric vehicles that can absorb grid capacity? BTM storage largely unregulated, needs regulatory attention to achieve efficiency, cost-effectiveness, quality, and public good vs private gain*

"Behind the meter" storage is a new and largely untapped horizon for the electricity grid. Government can support innovation not only in new battery technology but also in measures that will bring significantly greater service to rate-payers.

With the advent of rooftop solar, the distribution grid now has the challenge of two-way electricity flow among customers in a formerly one-way system. Energy storage can play a major role in addressing this two-way flow challenge, especially when coupled with digital energy management and a proliferation of distributed energy resources such as electric vehicles, demand charge management, time-of-use management, and back-up power (Deora 2017).

The rapidly growing need for electric vehicle charging is an especially fertile area for battery energy storage. Electric vehicles are estimated to increase electricity demand by as much as 38% by 2050, a significant new growth for electricity demand in the present era of flat or declining demand (Walton 2018). There are two negative potential consequences to this demand growth: it may require significant expansion of grid infrastructure, and it may increase greenhouse gas emissions from the grid if electric vehicles are charged from fossil resources.

Significant expansion of the grid can be avoided if electric vehicles are charged at off-peak demand times, such as overnight. As the grid is built to supply peak demand, which is typically 40% greater than average demand, there are, in principle, enough generation resources to supply the additional electric vehicle charging demand without building more infrastructure. However, peak demand generation is almost all natural-gas-based, so that operating it at off-peak times to charge electric vehicles adds unacceptable greenhouse gas emissions to electricity generation. Simply sending price signals to encourage off-peak charging using idle gas peaker plant generation is not enough to solve the electric vehicle charging challenge. To reap the full greenhouse gas benefit of electric vehicles, they must be charged exclusively with renewable electricity.

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Dr. George Crabtree**

To decarbonize transportation, not only must electric vehicles be deployed on a significant scale, but the grid must be converted to low carbon generation through greater deployment of renewable wind and solar as well as nuclear generation, and peak demand must be met by battery energy storage instead of by gas peaker plants. These trends are either already launched or ready to emerge: the levelized cost of utility-scale solar and on-shore wind is significantly lower than the levelized cost of gas peaker, nuclear, coal, and gas combined cycle generation (Lazard 2019), and the levelized cost of electricity from batteries competes with the levelized cost of electricity from gas peaker plants (BlombergNEF 2019, Lazard 2019). To decarbonize transportation, both of these trends need to be encouraged by federal incentives.

With regard to electric-vehicle charging needs, many actions could be taken to achieve greater efficiency, cost effectiveness, high quality, and a balance of public good vs. private gain. Possible actions include, for example:

- Charge electric vehicles only from renewable generation, not fossil generation, to decarbonize transportation and improve public health.
- Charge electric vehicles off-peak to avoid significant grid expansion.
- Provide charging convenience to electric vehicle drivers, including convenient locations and a spectrum of charging times from fast to slow.
- Provide a reasonable rate of return for charging station owners to encourage adequate investment and rollout.
- Provide affordable charging for electric vehicle drivers to encourage widespread electric vehicle deployment.

This is the time to establish support for an electric-vehicle charging infrastructure to ensure that a uniform set of practices is followed and to control the emerging charging infrastructure rollout before it becomes dominated by private agendas. The federal government has the power and authority to set the standards for national charging station rollout.

**Question 3:** *How can the public and private sectors best value the unique attributes of storage (resilience, national security, carbon avoidance, peak shaving, etc.) in wholesale markets, giving us a true cost equation that does not devalue distributed energy resources compared to traditional energy sources?*

Distributed energy resources are relative newcomers to the electricity grid, arriving well after the traditional grid was structured in policy and regulation as consisting of generation, transmission, and distribution, each with prescribed functions and subject to separate policy and regulatory requirements. Generation has changed dramatically in the last decade with the advent of significant intermittent solar and wind resources that behave very differently from traditional fossil generation. Solar+storage generation is now the clear low-cost choice in sunny areas of the country, creating virtual power plants that are fully dispatchable and do not conform to the traditional fossil division into baseload and peaker generation.

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Dr. George Crabtree**

Storage spans the generation-load spectrum, behaving like load when it is charged and like generation when it is discharged. Distributed energy resources such as electric vehicles, rooftop solar, stationary energy storage, and digital energy management perform well outside the traditional distribution grid concept of passive delivery of low-voltage electricity to consumers. These innovative technology developments have the potential to significantly raise the efficiency and effectiveness and lower the cost of grid operation. In many cases these technology developments are prevented from competing with traditional grid resources by outdated and inflexible policy and regulation. To achieve resilient, reliable, low cost, and low carbon electricity delivery and transportation, the policies and regulations of the electricity grid need to be revised to allow the technology innovations of the last decade to provide the full value of their promise. These include allowing distributed energy resources to compete in, for example, the wholesale electricity market that is traditionally restricted to the generation and transmission sectors of the grid.

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**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Mr. Mitch Davidson**

**Question from Senator Debbie Stabenow**

**Question:** Thank you for discussing the importance of pumped hydroelectric storage. In the town of Ludington, which lies along the shore of Lake Michigan, there is a pumped hydro plant that began producing electricity in 1973.
The Ludington Pumped Storage Plant, co-owned by Consumers Energy and DTE, is among the largest energy storage facilities in the world. It has the capacity to store and provide power to 1.4 million people.
Would you please elaborate on the unique ability of pumped hydro to provide steady and efficient electricity across periods of peak demand?

**Answer:**

Historically, most pumped hydro facilities – including the Ludington Pumped Storage Plant and our Bear Swamp facility – were located near large baseload generators. Those baseload generators ran most efficiently when they were allowed to run at or near full capacity and not ramped down, though there was not always sufficient demand for all of the supply. The pumped hydro plants took that excess supply off the grid during off-peak hours and returned the power to the grid during the peak periods when it was needed most.

Today, pumped hydro facilities are increasingly helping to bring more intermittent renewable sources onto the grid by storing their power during periods of excess supply and providing power when load is high and intermittent renewable production is low. For instance, pumped hydro resources can support California's abundance of solar (i.e., the "duck curve") or, in other parts of the country, large volumes of wind in the off-peak times of late evening and early morning. In Michigan, with over 2000 MW of installed wind capacity, and another 300 MW of wind under construction, the capabilities of generators like Ludington are even more important.

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Mr. Mitch Davidson**

**Questions from Senator Mazie K. Hirono**

**Question 1:** Mr. Davidson, you spoke about the value of pumped hydropower as an approach to energy storage and highlighted some of the obstacles to new projects. Kauai Island Utility Cooperative is investigating a pumped storage project at two reservoirs that could help meet 20% of the island's demand for power. What lessons you have learned about addressing environmental impacts and the interests of local residents and other stakeholders when developing pumped storage hydropower projects?

**Answer 1:**
The Bear Swamp pump hydro facility that we currently own was completed in 1974 by its original project developer. That developer navigated the initial stakeholder outreach in order to get the project licensed.
Bear Swamp is currently in the re-licensing process and we are actively working with the local community and other stakeholders.
We are currently exploring developing new pumped storage projects and we are using the lessons that we have learned from our experience relicensing hydropower projects of all types. Those include early outreach to stakeholders, anticipating questions and issues that could potentially become problems later in the development process, and maintaining a dedicated team specifically tasked with ongoing stakeholder engagement. Our hydropower facilities often bring significant benefits to the community, including recreation opportunities, flood control, and local tax revenue. We are committed to working constructively with all stakeholders, as we are required to do under a FERC license and as we believe we ought to do as a responsible presence in the community.

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Mr. Mitch Davidson**

**Question 2:** What role do you see for federal tax incentives in developing new pumped storage projects?

**Answer 2:**

Pumped storage projects require a large amount of initial investment. Federal tax credits can be very helpful in helping finance those projects, and it is safe to say that some projects might not be financeable without them. We are most concerned, as a company, when some technologies are incentivized and other - competing - technologies are not. We hope that pumped storage would be treated on a level playing field with any other energy storage technology, as hydropower should be treated on a level playing field with other renewable generation sources.

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Mr. Ben Fowke**

**Question from Chairman Lisa Murkowski**

**Question**: Nuclear plants in many electricity markets have been struggling over the last three years due to decreased electricity prices. Has Xcel looked into the potential to mitigate the impact of low electricity prices on nuclear plants using energy storage, either through electric, heat, or chemical energy storage options?

**Answer**: As I discussed in detail in my testimony, storage has a wide range of uses in the future American electric grid. I believe it can help address a number of issues that we face, and it may have some value in helping with some of the issues that the nation's nuclear plants are now facing. In fact, we are working with the Department of Energy to study the possibility of using our existing nuclear units to produce hydrogen, which could act as an energy storage medium and provide another outlet for the units' energy output. However, this technology is years from commercial deployment. The immediate problem confronting many of the nation's nuclear plants arises from issues in the energy market. Until the regulatory challenges associated with those market issues are addressed, storage will play at most a small role in helping alleviate the price burden that the plants bear. We are fortunate in that our Minnesota nuclear units are well-run, low priced plants operating in a state with that has traditionally provided support for their operation. We will continue to evaluate how storage and other technologies can enhance the value of those plants for our customers.

**Question from Senator Debbie Stabenow**

**Question:** As you may know, I recently introduced the *Driving America Forward Act* to accelerate the adoption of electric vehicles by ensuring the federal tax credits remain available for the purchase of electric and fuel-cell vehicles.

Transportation is the leading source of emissions in the United States, and the widespread adoption of electric and fuel-cell vehicles can help us significantly reduce carbon emissions as well as local air pollution. Electric vehicles can reduce greenhouse gas emissions by up to 70 percent, and as the power sector becomes increasingly green, lifecycle emissions will drop further.

As the CEO of an electric utility, I am interested to hear your perspective on the role that utilities play in accelerating the deployment of vehicle charging infrastructure and any challenges that you see ahead. For example, with respect to resource planning, how is your company considering the impacts of increased electric vehicle adoption on electric generation, transmission, and distribution?

**Answer**: First, I'd like to commend you, Senator Stabenow, for being such a leader on transportation electrification. Your legislation will help provide certainty to consumers, utilities, and automakers as we partner on reducing emissions from the transportation sector. I am personally very excited about the possibilities of electric vehicles. While barriers remain, I am confident that electric utilities can play a valuable role in fostering their adoption and creating a real market for EVs.

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Mr. Ben Fowke**

As you note, transportation is now the leading greenhouse gas emitter both nationally and in some of the states Xcel Energy serves. As we move our system to 80% lower carbon by 2030 and 100% carbon-free by 2050, declining carbon intensity per kWh will mean we can increasingly reduce GHG emissions from the transportation sector as well. Meanwhile, flexible loads like EVs will help us integrate more variable resources like renewables into our fleet.

We see a few key barriers to adoption. The first (and likely biggest) is still the added upfront cost of an EV; that's perhaps not one that utilities can do much to address, but your bill could provide critical support on that front. Meanwhile the barriers that we think electric utilities like Xcel Energy are well positioned to address include:

a) *Awareness and education*. We are helping our customers understand the technology, charging options, affordable EV charging rates, environmental benefits of owning an EV, etc.
b) *Charging infrastructure*. This is our core business, and we can help prepare our communities. We are working to create the infrastructure for all types of charging – at home, for EV fleets, fast charging in public locations like highway corridors and community hubs, etc. This can both help defray the cost of charging and alleviate range anxiety that is a barrier to EV ownership for many.
c) *Energy optimization*. The cost of electricity can vary quite a bit based on how and when it is used, so utilities need to be involved in planning and optimizing the flow of energy. We can also do a lot to address the issue you raise: enabling EV growth while minimizing the need for new electric generation, transmission and distribution. We do this primarily by piloting time-of-use rates and technological controls that enable EV charging to be managed to off-peak hours and times of high renewable generation, reducing the need for incremental generation and distribution investments.

We are working to enable EV adoption in our states in a number of ways. First, we are supporting some the early adopters (like Metro Transit in the Twin Cities, City of Denver, and others) and developing solutions that will be broadly available over time. Second, we are electrifying Xcel Energy's own fleet where appropriate. Third, we are beginning to include transportation uses in our resource plans and other business forecasts. This is a very small part of our load right now, and will continue to be small for the next decade, but we see a tremendous future and we will be ready.

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Mr. Kiran Kumaraswamy**

**Questions from Chairman Lisa Murkowski**

**Question 1:** One of the benefits of energy storage resources is their ability to store power when it is generated – often when the power is the least expensive – and dispatch that power during periods of peak demand. How does this ability to serve as a peaking resource ultimately lower energy costs for consumers?

When storage is used to provide peaking power, it can lower energy costs in a number of ways. For commercial and industrial customers, using storage means they can reduce demand charges – which are based on their peak usage and can be a major part of their electric bills. For some utilities – such as municipals or electric cooperatives that buy their power from others – using storage to "peak shave" likewise means they can cut demand or peak pricing, with savings that can be passed through to their customers. Also, using storage for peaking power may mean a utility does not have to build new distribution lines or other infrastructure to meet its peak demand, providing more savings for the utility and its customers.

**Question 2:** When it comes to energy storage, our growing dependence on China and other countries for all needed battery materials is a glaring strategic national security vulnerability. Additionally, the U.S. is ceding this emerging industry to Asia and making deployment less certain. Please explain whether the sourcing and supply chain for batteries or other components of your systems have been a challenge and how that might change as penetration of this technology increases? Do you think it is important that we increase domestic production of batteries and battery materials?

Fluence is a technology agnostic energy storage solutions and services company. We work with various companies and technologies to deliver systems with the lowest lifetime cost and the highest-quality solution for our customers. We source the components that go into our storage system from vendors around the world, ensuring enough diversification in the supply chain to protect us from any potential downside related to geopolitical issues. That said, we would highly welcome opportunities to increase domestic production of batteries, which would allow us to source locally.

**Question 3**: Alaska is home to many remote communities that are powered by microgrids, but often with diesel generation. The goal is to displace this diesel generation with renewable resources. How can batteries help remote communities in Alaska and elsewhere integrate more renewable energy resources? What other storage technologies are available?

Certainly, storage can help integrate a range of renewable generation – solar, wind or hydro – which could open-up a range of options for remote communities seeking to develop microgrids and reduce their dependence on diesel or other fossil fuels. For grid-edge communities – still connected to the grid but at its farthest reaches – storage can help to defer expensive distribution upgrades (as occurred with the Fluence storage project in Punkin Center, Arizona). Longer duration storage can also provide ongoing power for critical infrastructure during power outages, without having to fire up a diesel generator.

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Mr. Kiran Kumaraswamy**

**Question 4**: Many energy storage technologies, including batteries and pumped hydroelectricity, have certain operating limitations in terms of temperature. Are there any difficulties in developing large scale battery storage technologies in places like Alaska where the temperature can drop below -20 degree Fahrenheit? What energy storage technologies are best for use in extreme temperature environments?

Fluence has delivered energy storage systems in varying geographies with extreme temperatures. We do not anticipate any significant issues in designing or delivering a solution in Alaska. We would follow the appropriate design principles to account for local conditions like temperature and humidity.

**Questions from Senator Debbie Stabenow**

**Questions:** Energy storage has the potential to transform all aspects of our electric grid. As you've highlighted in your testimony, this technology is critical to optimal grid performance and the successful integration of renewable energy.

How can energy storage solutions specifically benefit rural communities, which often pay some of the highest energy costs and face unique reliability challenges? Additionally, may you explain how energy storage can not only improve reliability for rural communities, but also help rural electric cooperatives and utilities in these markets save money by deferring or avoiding costly infrastructure investments?

Storage can provide enormous flexibility – and different value streams – for small, rural communities. Again, Punkin Center is a great example of a small, desert community with growing power demand. In this case, using storage meant the town's utility – Arizona Public Service – was able to defer upgrading 17 miles of poles and wires over very rough terrain. In other instances, storage might be able to provide a small utility multiple value streams – allowing them to save money on infrastructure upgrades and demand charges, while also supporting local business growth.

**Questions from Senator Mazie K. Hirono**

**Questions:** As a member of the Senate Armed Service Committee, I have pressed the Department of Defense to define and measure energy resilience, then follow through with cost-benefit analyses of improving energy resilience at military installations, including using energy storage systems. You testified about a critical need for the Department of Energy to measure the value that energy storage can provide to the resilience of the larger grid. Could you elaborate on the need for, and benefits of, the DOE quantifying the value of the resilience that energy storage can provide? Are there particular objectives or parameters for the study that you would suggest to DOE to increase the benefits of such a study to the power industry and resilience planners?

Integration of energy storage resources provides various benefits to the grid. However, while some of the benefits can be monetized through wholesale market products and services, several categories of benefits are not fully compensated in our wholesale power markets. The ability of energy storage to provide

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Mr. Kiran Kumaraswamy**

resiliency to the wider electric power grid fits in this category. Additional examples of such benefits of storage are, (1) Efficiency increase in existing thermal generation plants when paired with energy storage, leading to reduced emissions. (2) Enabling traditional generation facilities to start up and stop less frequently, reducing maintenance and fuel costs, and reduces curtailment of intermittent renewable generation. None of these benefits are currently compensated by our power markets. The best way to address this would be to reform wholesale market products to reflect these benefits; however, we recognize this would be a long and arduous process, one that takes several years. In the interim, policies such as an investment tax credit for standalone energy storage could serve as a proxy for these currently uncompensated categories of benefits that storage delivers for our electric grid.

**Question from Senator Angus S. King, Jr.**

**Question:** How can the public and private sectors best value the unique attributes of storage (resilience, national security, carbon avoidance, peak shaving, etc.) in wholesale markets, giving us a true cost equation that does not devalue distributed energy resources compared to traditional energy sources?

Careful valuation of the multiple value streams of energy storage is critical to optimize its use in our wholesale transmission system. But it is also extremely complex. As noted above, many of the benefits storage can provide are not yet well or fully compensated in our wholesale markets. A thorough-going reform is needed, involving both FERC and possibly state regulatory bodies.

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Mr. Andrew Ott**

**Questions from Chairman Lisa Murkowski**

**Question 1:** One of the benefits of energy storage resources is their ability to store power when it is generated – often when the power is the least expensive – and dispatch that power during periods of peak demand. How does this ability to serve as a peaking resource ultimately lower energy costs for consumers?

**PJM Response:**
Serving as a peak power resource, energy storage has the potential to lower the cost of electric service for consumers primarily in two ways. First, deploying energy storage resources can lower the cost of energy during peak times if the cost of storing energy during off-peak times and discharging that energy to the grid during on-peak times (plus any losses) is cheaper than the incremental cost of dispatching a thermal power plant during on-peak times. For example, if an energy storage resource charged or pumped at night at a cost of $20/MWh and was willing to return that energy to the grid at $35/MWh, it would be cheaper to use that resource during a peak hour than to dispatch a $36/MWh unit to serve that same increment of load. This is a simplistic example to illustrate the point.In reality, physical constraints in the transmission network can affect which units are dispatched to serve load during peak times, which could result in the storage resource (or any resource) not being dispatched despite it being more cost effective. Moreover, the degree to which energy storage resources can be used to provide energy relates to their duration before needing to recharge, an issue highlighted in Mr. Ott's testimony.

Second, energy storage resources that have the duration to provide energy over a peak period can be valued for the resource adequacy they contribute to the system. In PJM, resource adequacy is valued through a capacity market, called the Reliability Pricing Model. Energy storage resources that offer and clear in the PJM capacity market may be less expensive than another resource offering into that market, and therefore can provide savings or downward pressure on future capacity costs for consumers. To date, hydro facilities are candidates for serving as capacity resources, although PJM would similarly accept any storage resource that can meet the FERC-approved capacity obligations needed to ensure a reliable system. PJM looks forward to FERC's ruling on the aggregation of distributed energy storage resources, as aggregation may be another means for energy storage resources to qualify as capacity resources in the PJM market.

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Mr. Andrew Ott**

These are ways in which energy storage as a peaking resource could lower energy costs for consumers at the wholesale level, affecting all or a multitude of consumers across a wide area.It should be noted that in addition, there are individual customer-level benefits that energy storage can provide at the distribution level. The opportunities for energy storage at the distribution level are highly dependent on the state-regulated distribution tariff under which a customer takes electric service from the utility, or ways in which the distribution utility itself can use storage as a peaking resource to lower their costs to reliably serve consumers.

**Question 2:** PJM is the largest wholesale market in the country, serving 65 million people from Chicago to the Atlantic Coast. What are some of the challenges of incorporating energy storage into such a large market? What benefits do you expect to see as the grid continues to add more energy storage?

**PJM Response:**
The size of the PJM market has actually provided benefits in terms of more efficient dispatch, market settlement and interconnection of energy storage resources. Nevertheless, the competitiveness of the markets in PJM today may create challenges for storage development. The PJM Energy Market has been producing historically low prices in recent years, largely due to the exit of older, less-efficient power plants and the influx of new, highly efficient and lower-cost natural gas plants, as well as renewable resources.

Energy storage resources clearly have the ability to increase the utilization of existing generation and transmission assets on a system-wide basis. As a result, benefits may include more efficient dispatch of generation and the potential for lower costs and lower emissions. Widespread deployment of energy storage may also have the ability to reduce losses on the transmission system or distribution system, depending on the energy storage resource's location and utilization. Finally, flexible resources such as batteries can help with the challenges of balancing fluctuations in demand for electricity and, increasingly, fluctuations in variable wind and solar output. These fluctuations are most impactful in smaller markets with extensive wind and solar deployment and less fossil resources available to help manage those fluctuations. Nevertheless, these issues exist in the PJM market as well and will increase over time as more renewable resources are deployed. It is for this reason that PJM has sought to more appropriately

**U.S. Senate Committee on Energy and Natural Resources**
**June 4, 2019 Hearing**
***Opportunities for the Expanded Deployment of Grid-Scale Storage in the United States***
**Questions for the Record Submitted to Mr. Andrew Ott**

value resources held in reserve as specified in our Enhanced Price Formation in Reserve Markets filing in Docket No. EL19-58-000, now pending before the FERC.

As noted in Mr. Ott's testimony, today's limited duration of batteries does limit the ability of PJM to treat and compensate these resources as capacity the same as fossil resources or demand response resources that are available upon call. We look forward to continued technological development in this area. In the interim, PJM will continue to still provide these resources with credit for the amount of capacity they would be able to provide just as PJM does today with renewable resources.

**Question from Senator Angus S. King, Jr.**

**Question:** Pumped storage and batteries generally have high capital costs and low operating costs. Current financing drives investors and development towards low capital cost investments like natural gas. Can you expand on potential mechanisms to help develop capital intensive applications like pumped storage and batteries, such as long-term contracting?

**PJM Response:**
By operating a forward capacity market, the PJM markets send a reliable investment signal as to the costs and opportunities for financing new technologies in the PJM markets. In addition, while the markets that PJM operates are generally hourly in nature, (except for capacity which is an annual commitment), there is nothing that impedes generators from contracting bilaterally with load or financial markets under longer-term agreements. In fact, long-term contracts are common in PJM and, indeed, are an implicit goal of the design for the spot markets that PJM administers – transparent spot market pricing from the PJM markets generally serves as a reference point for such contracts.

In the past, PJM stakeholders have discussed longer-term market products (e.g., multi-year) but the credit requirements associated with longer-term forward positions in the market have been a formidable barrier to stakeholder acceptance. Several policy initiatives that Mr. Ott summarized in his testimony and which are still awaiting decision at FERC should enhance the options for capital-intensive technologies such as energy storage. Specifically, PJM's Enhanced Price Formation in Reserve Markets filing (Docket No. EL19-58-000) is an important market design enhancement that will improve energy-reserve price

formation, thereby sending more accurate market signals that reflect the value of reliability and mitigate the missing money problem that has impeded efficient investments in capital-intensive applications.

April 29, 2019

The Honorable Chuck Grassley
Chairman, Senate Finance Committee
219 Senate Dirksen Office Building
Washington, D.C. 20510

The Honorable Ron Wyden
Ranking Member, Senate Finance Committee
219 Senate Dirksen Office Building
Washington, D.C. 20510

Dear Chairman Grassley and Ranking Member Wyden:

We are writing jointly on behalf of the environmental, conservation and renewable energy organizations signed below to respectfully urge enactment of an energy storage tax credit as part of any "extenders package" considered this year.

Specifically, we ask that energy storage be considered an eligible technology for the Section 48 and Section 25D 30% investment tax credits (ITC). Currently, energy storage technologies are only eligible for the investment tax credit as part of hybrid projects, under specific and relatively limited circumstances. Clarifying energy storage's full eligibility for the ITC would accelerate energy storage deployment, improve power system reliability and resilience, and optimize the nation's renewable energy resources.

An energy storage tax credit is a shared priority for extenders legislation. Such a credit provides a uniquely near-term and impactful way to accelerate the transition to renewable energy, spur economic growth, and reduce greenhouse gas emissions.

We thank you for your consideration and for your support of America's growing renewable energy sector. We would of course welcome the opportunity to meet and discuss this vitally important measure.

Sincerely,

American Council on Renewable Energy
Environment America
Environmental Defense Fund
League of Conservation Voters
National Audubon Society
National Wildlife Federation
Natural Resources Defense Council
Sierra Club
Union of Concerned Scientists

Cc The Honorable Nancy Pelosi, Speaker of the House
The Honorable Steny Hoyer, House Majority Leader
The Honorable Kevin McCarthy, House Minority Leader

National Hydropower Association
601 New Jersey Ave. NW, Suite 660, Washington, DC 20001 • Tel 202.682.1700 • Fax 202.682.9478 • www.hydro.org

June 12, 2019

The Honorable Lisa Murkowski
Chairman
Committee on Energy and Natural Resources
Resources
304 Dirksen Senate Office Building
Washington, DC 20510

The Honorable Joe Manchin
Ranking Member
Committee on Energy and Natural
Resources
304 Dirksen Senate Office Building
Washington, DC 20510

**Re: Statement for the Record of the National Hydropower Association (NHA) on the June 4, 2019 hearing on expanded deployment of grid-scale energy storage in the United States**

Chairman Murkowski and Ranking Member Manchin:

The National Hydropower Association (NHA)[1] wishes to express its great appreciation for your leadership on energy storage issues and for holding the hearing on June 4, 2019 focusing on "expanded deployment of grid-scale energy storage in the United States." We were pleased that pumped storage hydropower was represented on the witness panel by both Mitch Davidson, CEO, US Brookfield Renewable and Ben Fowke, Chairman of the Board, President & Chief Executive Officer, Xcel Energy Inc. We were also pleased with the recognition by you and your colleagues of the many grid benefits, including renewables integration, that pumped storage has provided the U.S. system for many years.

**Background**

As was mentioned in the hearing, pumped storage hydropower is currently the largest provider of energy storage in the U.S. today, making up roughly 95 percent of the market.[2] Existing pumped storage projects are located across the country from the Northeast to California with an installed capacity of approximately 22,000 MW.[3]

[1] NHA is the national non-profit trade association dedicated to promoting the growth of clean, affordable, U.S. waterpower technologies – hydropower, pumped storage, marine energy and conduit projects. It seeks to secure their place as renewable and reliable energy sources that serve national environmental, energy, and economic policy objectives. NHA's membership includes more than 240 companies, from Fortune 500 corporations to family-owned small businesses. NHA members include public and investor-owned utilities, independent power producers, developers, equipment manufacturers and other service providers. NHA's Pumped Storage Development Council brings together interested companies to discuss and address emerging policy and business needs for the sector.
[2] 2017 Department of Energy Hydropower Market Report, Executive Summary, P.2.
https://www.energy.gov/sites/prod/files/2018/04/f51/Hydropower%20Market%20Report%20-%20Executive%20Summary.pdf
[3] Ibid. P.2.

While many of the projects in the U.S. were built decades ago, new pumped storage projects have continued to be deployed around the globe to help countries maintain reliable and resilient power grids. The increased deployment of other renewable resources, such as wind and solar, in the U.S. has amplified the reliance on existing facilities and is spurring a resurgence in developing the latest in pumped storage technology.

The pumped storage sector has the potential to see a great renaissance. Currently, there are nearly 30 projects with active preliminary permits at the Federal Energy Regulatory Commission (FERC) pursuing licenses representing over 16,000 MW of new capacity[4] with several additional projects that have recently completed the licensing phase and are near ready for construction.

**Grid Benefits**

Pumped storage, as well as conventional hydropower with reservoir storage capability, serves as an integrator of variable renewable resources, allowing for greater penetration of wind and solar projects, while also ensuring grid reliability.

These projects can provide all components of reliability, including: energy generation, flexible capacity, voltage support, regulation, spinning and non-spinning reserves, storage, inertia, as well as blackstart capability. As policymakers pursue the dual objectives of a cleaner energy portfolio and enhanced reliability, promoting projects with the ability to provide these services is increasingly important and needed.

In the DC region and across the country, the attributes of pumped storage and hydropower are being increasingly recognized by grid operators as essential to the safe and reliable functioning of the grid system. In PJM's 2017 Evolving Resource Mix and System Reliability Report[5], hydropower was rated as the resource that provides the most grid reliability and resiliency services.

The Report identified 13 generator reliability attributes. These included: 1) essential reliability services (frequency, voltage and ramp capability); 2) fuel assurance; 3) flexibility; and 4) other attributes (blackstart, no environmental restrictions, equivalent availability factor). PJM found hydropower to provide some or all of the needed attribute for 12 of the 13 – the best result of all the resources analyzed.

As Andrew Ott, President and CEO, PJM Interconnection LLC, stated in his written testimony, PJM has over 5000 MW of pumped storage in its system compared to 300 MW of batteries and 20 MW of flywheels. It is pumped storage, along with the thousands of megawatts of hydropower, that is serving as the backbone for the PJM system.

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[4] FERC data on issued preliminary permits for pumped storage, February 1, 2019. https://www.ferc.gov/industries/hydropower/gen-info/licensing/pump-storage/issued-permits.pdf

[5] PJM's Evolving Resource Mix and System Reliability, March 2017, P. 16. https://www.pjm.com/~/media/library/reports-notices/special-reports/20170330-pjms-evolving-resource-mix-and-system-reliability.ashx

As such, one would presume that the environment for additional pumped storage deployment is a favorable one. From a power system standpoint, this is true. However, there are a variety of regulatory, energy policy, and market challenges that are severely constraining the deployment of new pumped storage resources.

**Policy Issues**

The U.S. energy landscape has seen tremendous change in the last 10 years and will continue to see drastic change over the next several decades as the transition to a 21st century power grid includes a greater reliance on clean, no and low-carbon technologies, and increased use of distributed energy resources. Without the addition of more energy storage, new transmission, combined with the continued growth of flexible baseload generation with load following capabilities, this transition has the capability to significantly impact grid reliability and resiliency.

NHA believes a successful transition requires U.S. energy, environmental and market policies to support greater use of technologies that provide flexibility to our system. As such, NHA also believes that pumped storage and conventional hydropower, both existing projects and new development, are a lynchpin to this transition. However, if Congress and local policymakers do not address the barriers, the contributions of these resources will not be maximized. Some of these issues include:

Licensing Reform – NHA appreciates the recent, and ongoing, work of Congress to fix the outdated regulatory process for hydropower and pumped storage, but more needs to be done. These projects have the longest, most complex timeline of any renewable energy or storage technology. The licensing process itself is uncertain, and can take 10 years or longer and cost tens of millions of dollars. In addition, new licenses can cost tens or hundreds of millions of dollars to implement. NHA strongly urges policymakers to take a fresh look at maximizing the efficiencies of the regulatory process if they want to promote new projects, and keep existing projects online, to serve a modernized electric power grid.

For this reason, in the 115th Congress, NHA supported the comprehensive hydropower licensing provisions of the bipartisan Senate energy bill, S. 1460. NHA also supported H.R. 3043, the Hydropower Policy Modernization Act, which passed the House on a bipartisan basis. While some of the provisions contained in these bills were included in S. 3021, the America's Water Infrastructure Act (AWIA), which was signed into law, most were not. We look forward to continuing our work with the Committee to adopt further regulatory efficiency improvements in this new Congress.

Tax Credits – Currently, there is no federal tax incentive that supports the deployment of new energy storage resources, including pumped storage hydropower. The U.S. has long used targeted tax incentives to leverage investment and innovation in the energy sector. This is true for fossil and renewable resources alike. Hundreds of thousands of

jobs and billions of dollars in private investment across the industries – not to mention gigawatts of affordable, reliable, and renewable power – have been driven by tax policies. As such, NHA supports the adoption of an energy storage investment tax credit (ITC). Bills have been introduced in both the Senate (S. 1142) and the House (H.R. 2096) proposing a storage ITC, which include pumped storage as an eligible technology. We strongly urge quick passage of the legislation.

Additionally, the tax credits for conventional hydropower have been expired since 2017. while other renewable resources, such as wind and solar, have enjoyed years of certainty with long-term extensions. This treatment has put hydropower development at a severe competitive disadvantage in the market for new renewable electricity generation, particularly for investors seeking clarity and certainty.

Certainty in tax policy is needed to accommodate the longer development lead times for projects in the hydropower sector. Also, new facilities, in particular, are often highly capital intensive and tax credits are an important tool for attracting tax equity capital investment. NHA urges Congress to pass an extenders bill (such as S. 617, the bipartisan Tax Extender and Disaster Relief Act of 2019), that includes extension of the tax credits for hydropower projects. NHA also believes a long-term extension of the credits is warranted.

Energy Market Recognition and Valuation – To be a viable resource option, and to be sustainable over the long term, an equitable market must send appropriate price signals to hydropower and pumped storage owners and operators. Markets fail when they value only some attributes (such as energy) while still transferring the benefits of other attributes (such as associated grid services) without prescribing a value on those services. Policymakers must ensure that grid benefits are appropriately compensated, or they risk losing those key services if projects are not able to justify continued operation due to poor economic conditions.

This is a policy area that involves federal, state and regional actors. From the Congress and FERC, to the independent system operators (ISOs) and regional transmission organizations (RTOs), to state energy policy officials and regulators. While NHA is beginning to work more directly in the states and regions, we also encourage the Committee, in its oversight capacity, to highlight this issue and raise awareness of the need to address these market gaps and inequities.

Finally, I would also like to address the Committee's attention to two recent NHA resources for more information. The first is a 2018 white paper[6] on pumped storage. The second is a new hydropower white paper[7] issued in April 2019. Both documents provide a more detailed

[6] https://www.hydro.org/wp-content/uploads/2018/04/2018-NHA-Pumped-Storage-Report.pdf
[7] https://anf5l2g5jkf16p6te3ljwwpk-wpengine.netdna-ssl.com/wp-content/uploads/2019/04/Reinvigorating-Hydropower.pdf

discussion and analysis of the history, current market environment, and policy needs for these resources.

NHA hopes that the generation, flexibility, storage, and other important attributes of hydropower and pumped storage projects will be more fully valued in energy policy as we work to ensure the reliability of the electricity grid. NHA appreciates the opportunity to present this statement for the record in response to the hearing and look forward to working with the Committee more on these issues in the future. If there are any questions, please feel free to contact me at 202.750.8403.

Sincerely,



Jeffrey A. Leahey
Executive Vice President for Governmental Affairs