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EXAMINING THE STATUS OF ENERGY STORAGE TECHNOLOGIES, REVIEWING TODAY'S TECHNOLOGIES AND UNDERSTANDING INNOVATION IN TOMORROW'S TECHNOLOGIES

HEARING

BEFORE THE

COMMITTEE ON ENERGY AND NATURAL RESOURCES UNITED STATES SENATE

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TUESDAY, OCTOBER 3, 2017

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

The Committee met, pursuant to notice, at 10:32 a.m. in Room SD–366, Dirksen Senate Office Building, Hon. Lisa Murkowski, Chairman of the Committee, presiding.

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

The CHAIRMAN. Good morning. The Committee will come to order.

We had originally scheduled a business meeting of the Energy Committee to consider two nominees for the Department of Energy (DOE), but we have not been able to arrange for a sufficient number of members to advance them, so we will alert members to when we will take that up, likely after the next scheduled vote. It is my understanding there are no votes scheduled for today, so I do not anticipate that we will have this today. It is my intention, again, to try to advance not only these nominees out of Committee but those that have been moved to the Floor so that hopefully we can get some of the teams filled up.

Today we are here to conduct an oversight hearing to consider the status and the future of energy storage technologies. We have all heard about the benefits that can be associated with the deployment of energy storage, including increased grid reliability and resilience. As we think about "reliability and resilience," we recognize they really have taken on even greater meaning in the wake of several recent natural disasters.

Of course, our prayers continue to go out to all those who have been impacted, whether they be in Texas, Louisiana, or Florida and, of course, those who are facing the most desperate situation right now and those are the Americans that live in our island territories. Puerto Rico and the U.S. Virgin Islands are in a state of emergency right now. Our top priority is to make sure that local residents have food, water, medicine, and shelter.

I have notified all members of this Committee as well as the Appropriations Committee that we are looking to travel to the area as soon as the situation has stabilized enough for us to do so. I would also anticipate that we will be holding a hearing about the status of the recovery and our options for rebuilding.

There are some quick steps we can take, like the confirmation of well-qualified nominees with expertise that can be put to use in the response effort. Bruce Walker, who was before the Committee last week as the nominee to lead the Department of Energy's Office of Electricity, I think, is a pretty good example of that. But there are also some longer-term steps that we can take and that we should already be thinking about.

At the top of that list is how we can help rebuild the grids of Puerto Rico and the Virgin Islands. While the Virgin Islands' grid is not in as difficult of shape as Puerto Rico, I think we recognize that the situation on the ground is something that needs to be addressed. We urgently need to restore electric power, but we also need to be looking for ways to make those grids more reliable and more resilient than ever before. Energy storage really has to be considered in that conversation, just as it has been part of our policy conversations here in the Committee throughout this year.

In June, we held a hearing on cost trends in emerging energy technologies that included energy storage. We learned a little bit about how costs are decreasing while opportunities are increasing.

Shortly after that, we had a field hearing in Cordova, Alaska, to learn how hybrid microgrids can facilitate the integration of various renewable resources while reducing costs and increasing reliability. I tell my colleagues here on the Committee all the time, so many of our remote communities in my state are completely disconnected from a traditional grid. We truly are islanded in that sense.

We are innovating in some unique ways, bringing local resources together to decrease dependence on expensive diesel generation. So whether it is 60 below in Alaska and you are trying to stay warm, or 100 above somewhere in the South and trying to stay cool, we need reliable and resilient systems, and storage technologies like flywheels and batteries are vital to making them work.

Today's energy storage technologies are finding market applications for a host of different value streams that they provide such as frequency regulation, spinning reserve, load leveling, peak shaving, power quality, and capacity firming.

We have a lot to gain by advancing energy storage technologies, but that will also require innovative solutions to some very real challenges. Each type of energy storage technology has its own specific physical attributes, based on the physics that enables it. These can be well-suited for certain applications, but perhaps not so well-suited for others.

Today's burgeoning lithium-ion battery markets, and other future energy storage technologies, will also provide serious challenges to our minerals supply chains. We already import at least 50 percent of 50 different mineral commodities. We cannot allow that to worsen as these technologies grow in use.

Once energy storage technologies are designed and manufactured, they also have to carve out market applications that match the value streams that they can provide. So we need to ensure that federal policies do not unintentionally hinder the evolution of markets for this sector.

Energy storage offers great opportunities and I think we need technologies, resource supply chains, and markets that are prepared to take full advantage of them.

I look forward to hearing about the successes of today's technologies and learning more about what we expect to see in the future.

I thank the gentlemen who have agreed to join us here this morning on our panel. With that, I turn to Senator Cantwell for her comments this morning.

STATEMENT OF HON. MARIA CANTWELL, U.S. SENATOR FROM WASHINGTON

Senator CANTWELL. Thank you, Madam Chair, and I look forward to hearing from our witnesses today.

I, too, want to mention that we need to keep vigilant on the situation in Puerto Rico, as a Committee that has jurisdiction over that as a territory. I am hoping today that with the President's visit he will make a full declaration of emergency for the entire island. I know that there are some municipalities for which the declaration has not been formally made, but I hope it isn't because we don't have communication lines between those municipalities to make that.

As somebody who has seen a lot of natural disasters in my state, I am telling you that getting the declaration done as soon as possible is key. And we just need to flatten that issue as quickly as possible.

I still think we need a coordinator at the White House level for all the various agencies that are going to have to work on the recovery of Puerto Rico, and so I hope that the White House will still continue that. And I hope that one of the large shipping employers in both of our states, who has offered to get large-scale generators to Puerto Rico that could help provide much of the necessary power grid opportunities, will be taken advantage of very shortly. So, lots of work to do there, and thank you for your attention to that.

Today's hearing about storage as a new platform is an incredible machine opportunity with what we call "the grid." The grid was named one of the greatest inventions of the 21st century by the National Academy of Engineering, and it was a platform that had so many advances to it. Just like roads or waterways or communication networks, it is a great enabler.

We can think of storage like we think of the grid itself. Just as the grid has become a platform for innovation, storage can be part of a platform for the new innovative grid. Deployed across the grid with new battery storage technologies, the whole grid and its delivery system, if you will, can be turned upside down.

We in the Northwest dream of that, as it relates to probably more electric cars per capita than anybody in the nation. Why? Because we also have the cheapest electricity, and people dream of the fact that those could become storage vehicles, in and of themselves, and sell back onto the grid with the right enabling technology and thereby become a whole platform unto itself.

So, like a Swiss Army knife, storage can perform more functions as a single element than any other part of the grid and that scale, this flexibility, will create a new kind of system. It will open the possibilities of things we can't even see today.

We are starting to see growth in storage that we've already seen in renewables. Last year, 100 percent year-over-year growth in storage; today, prices for lithium-ion vehicle batteries have dropped 80 percent from six years ago; and in five years, GTM Research forecasts seven gigawatts of new storage, or 20 times higher than last year.

So, storage is here, and I'm sure that's what our panelists will tell us. And it's going to get even better and cheaper.

Federal funding will accelerate this innovation, and federal support can bridge the gap between basic research and commercial sales.

Now is not the time to be slashing our research budget. For example, the President has proposed cutting DOE's Office of Electricity storage program by 61 percent.

Meanwhile, Secretary Perry has embraced an obsolete view of the grid. On Friday, he asked FERC to adopt a radical proposal. This proposal would bail out coal and nuclear power plants at the expense of everyone else, raising electricity rates for other consumers. Natural gas, renewables, efficiency, storage, and most importantly, consumers, would all lose out in this proposal. I hope FERC rejects his unsolicited, backward proposal. Instead, FERC can accelerate removing policy barriers to new technologies, such as how to work with storage in the marketplace.

So I look forward to hearing from our witnesses today about this particular opportunity that's in front of us, and I hope that we can also draw lessons from the tragedy that we are seeing in Puerto Rico as it relates to what we can do to move forward to give us more opportunities to be more resilient and to build stronger efficiencies into our system.

Thank you, Madam Chair.

Senator STABENOW. Madam Chair, if I might?

The CHAIRMAN. Senator Stabenow.

Senator STABENOW. Thank you very much.

I will be going back and forth between the Finance and Energy Committees this morning, and if I am not able to get back I would like very much to enter questions into the record. I just would ask consent to do that, if I am not able to get back. Hopefully, I am going to be able to do that, but I am attempting my spot of "beam me up Scotty" and trying to be two places at once, as we always do.

So, thank you.

The CHAIRMAN. We understand that and appreciate your interest. Of course, your questions for the record will be included. Thank you for your interest in the importance of storage.

We are joined this morning by four individuals, all experts in their respective areas.

We will lead off the panel this morning with Dr. Vincent Sprenkle, who is the Technical Group Manager for the Electrochemical Materials and Systems Group at one of our national laboratories, Pacific Northwest National Laboratory (PNNL). Welcome.

He will be followed by Mr. Praveen Kathpal, who is the Vice President for AES Energy Storage. He is also the Chair for the Board of Directors for the Energy Storage Association. Welcome.

Mr. Simon Moores is with us. He is the Managing Director for Benchmark Mineral Intelligence. We will hear about the intersection between critical minerals and energy storage.

Our last panelist this morning is Mr. John Seifarth, who is the Director of Engineering at Voith.

Welcome to all of you.

Dr. Sprenkle, if you would like to lead off the panel this morning?

STATEMENT OF DR. VINCENT SPRENKLE, MANAGER, ELECTROCHEMICAL MATERIALS AND SYSTEMS GROUP, PACIFIC NORTHWEST NATIONAL LABORATORY

Dr. SPRENKLE. Thank you, Chairman Murkowski, Ranking Member Cantwell and members of the Committee. I appreciate this opportunity to testify today.

My name is Dr. Vincent Sprenkle, and I manage the Electrochemical Materials and Systems Group at Pacific Northwest National Laboratory in Washington State.

The research being conducted at PNNL is at the forefront of energy storage R&D and our scientists have been critical to innovations developed under several DOE programs, including the Office of Science's Joint Center for Energy Storage Research and the Office of Electricity's Energy Storage Program. In addition, PNNL is leading the vehicle technologies program Battery500 consortium, targeting a two to three times increase in the range of electric vehicles for the same weight of batteries we have today.

Across these programs, PNNL scientists leverage a unique suite of tools and facilities to develop prototypes and validate the performance of next generation battery systems. Since 2009, our staff have issued 375 peer-reviewed publications and been awarded 45 U.S. patents that have been licensed to 20 companies.

For the past eight years, my focus has been on grid-scale energy storage and that will be what I have in my testimony today.

As you had indicated, the past decade has seen tremendous growth in the energy storage market for both transportation and grid-scale batteries. Even with this growth, battery deployments still make up less than 0.1 percent of the U.S. electrical capacity and significant R&D challenges remain across the technical readiness spectrum that can lower the cost and improve the value proposition of energy storage.

Under the DOE Office of Electricity program, PNNL researchers have been instrumental in accelerating the development of technologies that will enable storage to have a greater role in improving the reliability, the efficiency, and resiliency of the electrical grid.

The program is closely aligned with the 2013 DOE Grid Energy Storage report, which identified four major challenges: cost competitive technologies, improved safety and reliability, standardized valuation methods, and industrial acceptance.

While the falling cost of lithium-ion batteries have enabled energy storage to be deployed on the grid for high value applications, other technologies like redox flow battery systems may ultimately prove to be lower cost and longer life solutions.

In 2010, PNNL researchers developed an improved vanadium redox flow battery electrolyte. Variations of this work have been licensed now to eight companies, including UniEnergy Technologies, or UET, who now employs over 60 people. To date they have installed 18 megawatt hours of commercial systems in the U.S. and abroad with another 365 awarded or under contract.

What's exciting about this is this technology has managed to achieve or come close to the cost parity with lithium-ion in about five years of commercial development compared with the 25 years it took for lithium-ion to achieve that same area.

The new chemistries we are developing today have the opportunity to even further reduce that cost structure. The U.S. R&D pioneered the innovation between most modern battery technologies, including the widely-used lithium-ion. We believe future R&D leadership in energy storage will require continued commitment across the following areas: one, integrated science and technology investments from advanced characterization and design tools of those next generation systems to experimental testing and validation can deliver technologies that meet the cost and technical requirements of a majority of grid applications; accelerating the commercialization of breakthrough technologies requires new manufacturing paradigms that can be developed that quickly move these ideas from the innovation to systems level that are cost-effective and can be validated; regional technology demonstrations with federal and state support are needed to build user confidence; and the technology can enable utilities across the country to more effectively and efficiently deploy the technology.

Finally, standardized valuation methods that accurately capture the value of energy storage for utilities and regulators are needed along with advanced controls that seamlessly integrate with different technologies and enable more autonomous operation.

In conclusion, we have seen energy storage make a significant impact in the market, but there is a continuing need across the entire innovation spectrum to reduce the cost and increase the performance to realize the full potential of the benefits energy storage can provide.

Unlocking the full potential of U.S. researchers to address the fundamentals of energy storage, discover new materials, and rapidly translate these discoveries into practical applications is necessary to ensure the U.S. remains a leader in this technology.

Thank you and I look forward to any questions you may have.

[The prepared statement of Dr. Sprenkle follows:]

Written Statement of
Vincent Sprenkle, Ph.D.
Manager
Electrochemical Materials and Systems Group
Pacific Northwest National Laboratory

Before the
United States Senate
Committee on Energy and Natural Resources

October 3, 2017

Chairman Murkowski, Ranking Member Cantwell, and Members of the Committee, thank you for the opportunity to testify in today's hearing on energy storage technologies.

My name is Dr. Vincent Sprenkle, and I manage the Electrochemical Materials and Systems Group at Pacific Northwest National Laboratory (PNNL) in Washington State. PNNL is a U.S. Department of Energy (DOE) multi-program national laboratory stewarded by the Office of Science. At PNNL, my group is focused on developing the next generation of battery technologies for energy storage applications and this will be the focus of my testimony.

My comments today will focus on three main areas:

1. Key technology breakthroughs achieved through PNNL's work on grid energy storage and how we have transferred those breakthroughs to the private sector.
2. Energy storage materials research being conducted at PNNL for next-generation electric vehicles.
3. Future research and development (R&D) directions for energy storage.

Background

The past decade has seen tremendous growth in the energy storage market, with significant increases in the number of energy storage systems sold for both the electric vehicle and stationary energy storage markets. Even with this growth, battery energy storage for transportation and grid-scale storage is still an early-stage application market. For example, in 2016, 160,000 electric vehicles were sold in the U.S.—accounting for roughly 1 percent of the 17 million vehicles sold. After a year of record growth, battery solutions for the stationary energy storage market are projected to reach 395 megawatts by the end of 2017 but will still only account for less than 0.1 percent of U.S. generation capacity. While additional robust growth in both battery storage markets is anticipated, significant R&D needs and opportunities remain for innovations across the technology-readiness spectrum that can lower the cost of energy storage while increasing performance, safety, and reliability.

The research being conducted at PNNL is at the forefront of energy storage R&D. It includes fundamental characterization of battery materials, development of next-generation materials to improve the desired performance of the battery, and creation of analytical models that can accurately represent the technical and economic impacts of real-world applications on battery performance.

DOE's Office of Electricity Delivery and Energy Reliability (OE) and Office of Science are the primary sponsors of grid energy storage research at PNNL. OE funds R&D of next-generation, cost-competitive energy storage technologies and works with industry stakeholders to ensure these systems are safe, reliable, and can meet the technical and economic needs of industry—all of which are essential to moving energy storage technologies to market. The Office of Science supports fundamental research in cutting-edge in situ characterization tools and first-principle materials design efforts, which are foundational to the development of the next generation of energy storage systems. These systems can ultimately cost less and perform better than the technology that is deployed today.

Energy storage R&D for next-generation electric vehicle batteries is supported at PNNL primarily by the DOE Energy Efficiency and Renewable Energy's Vehicle Technologies Office and is focused on developing and demonstrating new battery chemistries that can deliver two to three times greater energy density—resulting in longer driving range and lower cost compared to today's lithium-ion batteries.

Scientists at PNNL are able to leverage a unique suite of tools and facilities—from the advanced materials characterization instruments at the Environmental Molecular Sciences Laboratory (a DOE user facility) to PNNL's Advanced Battery Facility—to develop, prototype, and validate the performance of next-generation battery systems. For example, using the Environmental Molecular Sciences Laboratory's capabilities, PNNL is pioneering in situ characterization techniques that enable real-time evaluation of functioning electrochemical couples under transmission electron microscopy imaging and Nuclear Magnetic Resonance spectroscopy. These tools allow scientists to see the atomic and molecular processes that influence battery performance and lifetime, and they help us understand how battery materials are changing under actual charging and discharging conditions. These techniques are being applied today to several new battery materials being developed for DOE and industry clients and will provide the world with unparalleled insight into how various battery chemistries change during operation.

This research already is benefiting the nation. Since 2009, PNNL energy storage researchers have issued 375 peer-reviewed scientific publications and have been awarded 45 U.S. patents, which have been licensed to more than 20 companies. This research has been instrumental in accelerating the development of technologies that will enable storage to play a greater role in improving the reliability, efficiency, and resiliency of the electric grid and increase the driving range of electric vehicles.

Grid Energy Storage Research

Electric energy storage has long been a "holy grail" for grid operators—technology that can cost effectively improve the resiliency, reliability, security, and robustness of the power grid. Grid-scale energy storage presents a distinct set of opportunities and technical challenges. OE's Energy Storage Program supports a wide range of R&D and has identified four development priorities in its 2013 ***DOE Grid Energy Storage*** report.

Those priorities, which guide OE's investments in this area, are:

- The development of ***cost-competitive technologies*** through targeted scientific investigations of key materials and systems.
- ***Validated reliability and safety*** by independent testing of prototypic devices and understanding of degradation.
- Enabling ***standardization of energy storage valuation*** through industry, utility, and developer collaborations to quantify benefits and provide input to regulators.
- ***Industrial acceptance*** by facilitating highly leveraged, early-stage field demonstrations and development of storage system design tools.

Cost-Competitive Technologies: Falling costs of lithium-ion batteries and redefinition of market rules have enabled a significant increase in the amount of energy storage deployed for grid applications, such as short-duration frequency regulation. While lithium-ion chemistries were not designed specifically for grid services—and we don't fully understand the impacts of these services on their lifetime—they have proven the technical and economic viability of energy storage on the grid. Other battery technologies, like redox flow systems, may ultimately be a lower-cost alternative and contain sufficient energy capacity to enable these systems to meet multiple grid applications.

PNNL's pioneering work in vanadium redox flow batteries, which enabled a 70 percent increase in energy density and an 83 percent increase in temperature stability, overcame several of the barriers limiting flow battery commercialization, including cost competitiveness. Variations of this successful technology already have been licensed to eight companies. One such company, UniEnergy Technologies (UET), was started by two former PNNL scientists in 2012 and currently employs more than 60 workers at its facility, north of Seattle, Washington. To date, UET has installed 18.5 megawatt hours of commercial systems in the U.S. and abroad, and has an additional 365 megawatt hours under contract or award. This technology is starting to achieve cost parity with lithium-ion at a systems level after only five years of development—compared with the more than 25 years that lithium-ion cells have been in production. PNNL is currently developing the next generation of redox flow batteries, focused on replacing the vanadium species with engineered aqueous-soluble organic molecules that could further decrease the cost of flow battery systems by another 50 percent.

Validated Safety and Reliability: For energy storage systems to be ubiquitously accepted, the technology must be demonstrated to be safe and reliable. A scientifically-derived knowledge base must be developed and disseminated to industry that improves our understanding of the predictability of storage systems under a wide variety of conditions and enables the engineering of safer and more reliable systems. These efforts form the basis of new protocols, codes, and standards that ensure large-scale grid storage can be deployed safely and reliability.

At PNNL, researchers are evaluating the impact of grid services on battery performance and understanding how changes in the materials and interfaces are impacting the expected lifetime and safety of the systems. Along with Sandia National Laboratories, PNNL leads an Energy Storage Safety Working Group with stakeholders in the storage industry to focus R&D activity related to safety and to facilitate the development and deployment of codes, standards, and regulations affecting energy storage system safety. These efforts are critical to building consistency and uniformity in evaluating and ultimately deploying new battery technologies.

Enabling standardization of energy storage valuation: Science and technology efforts are critical to the deployment of energy storage, but alone cannot achieve the end state goal. Utilities at all levels—consumer-owned, investor-owned, municipalities—must have the capacity to understand the value of energy storage. State regulators need the same tools and data sets with which to evaluate energy storage, so they can provide the type of policy environment that leads to deployment.

Value propositions for grid storage often depend on identifying the institutional and regulatory hurdles to deployment and understanding how storage benefits can be evaluated when compared to other grid resources. At PNNL, staff are working with public service commissions across the country to provide the technical information needed to accurately evaluate the net benefits storage can provide to the system. In Washington and Oregon, PNNL is working with utility commission staff to develop planning tools that can both capture the monetized and non-monetized benefits of storage and provide an analytics framework for integrated resource planning that can accurately evaluate storage benefits.

This work complements research undertaken by the Grid Modernization Laboratory Consortium (GMLC), a strategic partnership between DOE and 12 national laboratories. The GMLC is developing a framework for valuation of the new grid technologies and concepts, including energy storage, so that government and industry stakeholders can work together to assess the benefits and costs of resilience improvement strategies. This partnership between DOE, national laboratories, states, and industry is an important collaboration in charting a timely path to a more resilient U.S. power system.

Industrial Acceptance: Demonstrating the economic value, performance, and reliability of early-stage energy storage systems in both controlled and fielded deployments is critical to achieving new technology validation. As part of Washington State's Clean Energy Fund, PNNL is performing technical and economic use case analyses, dispatch optimization, and performance monitoring in collaboration with five regional utilities that are deploying energy storage technologies for improved renewables integration and enhanced resiliency. This analysis will form the framework for systems-level analysis tools that can be used by utilities, regulators, and industry to accurately capture the locational value (monetized benefits and avoided costs) of energy storage deployments.

Most of the 3,000 utilities, municipalities, and cooperatives located in the U.S. have limited—or no—R&D budget to examine the benefits of storage. PNNL, along with partners at Sandia National Laboratories and Oak Ridge National Laboratory, is actively engaged in helping utilities understand the locational benefits energy storage can provide to their systems by developing analytical models that accurately capture the entire benefit proposition. As part the GMLC, PNNL staff recently completed a detailed analysis with Portland General Electric (PGE) on its 5 megawatt/1.25 megawatt hour Salem Smart Power Energy Storage Demonstration project. This study showed that PGE could utilize the facility for the Western Energy Imbalance

Market to derive an additional $150,000 in revenue every year, and that additional benefits could be realized as the energy capacity of the battery was increased to 10 times its current duration—resulting in clear economic value and performance increase while providing additional reliability to the system. Under the same project, our partner laboratories are working with Electric Power Board of Chattanooga, Tennessee to add energy storage to its automated power management system to form one of the most advanced smart grids in the country and serve as a living laboratory for future grid modernization technology.

Energy Storage Research for Electric Vehicles

Making electric vehicles with smaller, lighter, less expensive batteries requires research across multiple DOE programs. The Joint Center for Energy Storage Research (JCESR), funded through DOE's Office of Science, undertakes fundamental research to serve as a foundation to develop game-changing, next-generation battery technologies. Argonne National Laboratory leads JCESR, which includes other national laboratories, universities, and industry partners. DOE's Battery500 Consortium, funded through DOE's Energy Efficiency and Renewable Energy Office, is focused on doubling the energy storage of existing battery materials while also producing a high-performance battery that is reliable, safe, less expensive, and can be easily adopted by manufacturers. This is a significant challenge requiring technical expertise across the U.S. R&D sectors and PNNL, as lead of the Consortium, has the support of partners including other national laboratories, universities, and industry.

DOE's investments in advanced energy storage technologies will transform vehicle transportation. Today, lithium-ion batteries are the dominant technology for electric vehicles. On average, it takes 4.5 pounds of batteries to travel one mile. Meeting the Battery500 goals would enable that same 4.5 pounds of batteries to travel 2.5 miles, thereby increasing the overall range—or decreasing the cost of the electric vehicle when the range is kept constant. To accomplish this goal, the Consortium's aim is to double the "specific energy" of electric vehicle batteries. "Specific energy" measures the amount of energy packed into a battery based on its weight. Current batteries contain approximately 200 watt-hours per kilogram and will need to achieve 500 watt-hours per kilogram by the end of the program.

To meet the goals of the Battery500 Consortium, a novel approach is being used that integrates the best materials and battery researchers across the country to solve some of the most difficult science and technology challenges. For example, the Consortium will require replacing graphite with lithium-metal as the battery's negative electrode. Fundamental research will aim to understand how this new electrode interacts with other battery components and how to control those interactions to achieve the desired performance with a lifetime comparable to today's technology.

Future Research Directions

The U.S. pioneered the development of modern battery technologies, including the widely used lithium-ion batteries. Our leadership in this area is constantly challenged as the appetite for energy storage is growing around the world. Maintaining a leadership position in the next generation of energy storage technologies requires a continued commitment across the following areas:

- ***Science and technology investments:*** Sustained fundamental science and applied research is necessary to improve the tools and techniques available to develop the next generation of safe, low-cost, high-performance energy storage technologies. We cannot predict, based on scientific principles alone, the performance, safety, and reliability of new battery systems. Continued and focused research capable of understanding new energy storage systems at the component and interfacial level is required to address these challenges. New breakthroughs, based on these fundamental understandings, will take many years to ultimately yield low-cost, high-performance, and safe batteries for all applications. Ongoing developments in applied sciences—including sophisticated capabilities in materials synthesis, battery design/agile manufacturing, testing validation, and predictive computational tools, such as are available at DOE's national laboratories—are also required to move these technologies closer to practical realization. Integrated science and technology investments across the spectrum of fundamental science and applied research will ultimately yield technologies that can meet the cost and technical requirements of the market.

- ***Advanced Manufacturing/Prototyping:*** To accelerate the commercialization of breakthrough technologies, new manufacturing R&D is required to quickly move ideas from innovation to energy storage systems that are manufactured in the U.S. Common manufacturing architectures that provide a platform to accelerate the innovation coming out of universities, national laboratories, and small business can enable next-generation storage technologies to be validated and tested quickly and with minimal development time. There also must be a focus on the applied sciences to prototype and test these new systems at small-scale under real-word grid operating conditions. This is of particular importance for grid-scale storage, since the reliability and lifetime of new systems must be fully validated and understood before entering service on the grid. The information gained from this testing also provides the feedback loop needed for scientists and engineers to continue closing the gap between the often high theoretical potential of a new material and the much lower practical energy storage capacity and lifetime demonstrated in real-world systems.

- ***Technology Demonstrations***: Given the vast difference in expected lifetimes for grid storage (20-30 years) and transportation (5-7 years), additional technology demonstrations for grid technologies will be needed across the country to build confidence in the performance, lifetime, safety, and benefit to multiple low-cost grid applications. Energy storage demonstrations are taking place now with most new technologies receiving federal or state funding to share the risk with utilities. Continued demonstrations of energy storage in different regions of the U.S. builds confidence that energy storage is a viable technology option and can provide multiple grid services. Demonstrations that focus on validating life-cycle cost, performance, and safety for multiple grid applications, and that assess the overall benefit relative to grid reliability, resilience, and renewable integration, are critical to both long-term and near-term success in getting energy storage technology deployed on the grid. Additionally, with federal and state support, the lessons learned from these demonstrations can be shared across the entire utility community to enable those utilities with limited resources and opportunity to more effectively and efficiently determine where energy storage can contribute to their grid applications.

- ***Analysis and Control Systems:*** As the world moves towards a more decentralized electricity infrastructure, the impact of both electric vehicles and grid storage as a part of the suite of distributed energy resources (DER) must be analyzed and optimized to maintain desired reliability. Each of the more than 3,000 utilities in the U.S. will have different challenges and will recognize different benefits depending on the location and mix of these DER assets. Most utilities have little or no R&D capacity to fully analyze and determine the impacts of new energy storage systems or the increased adoption of electric vehicles. Uniform codes and standards—voluntarily accepted by industry—that allow interoperability between different technologies and software interfaces are required to ensure that new technologies can plug-and-play into the existing grid operations system when and where they are most needed. Advance controls must be developed that can autonomously determine the state of health of the energy storage system and determine the optimal energy dispatch parameters to reduce degradation and derive maximum value from the device. These control systems must be able to coordinate with other DER assets to aggregate for a specific service or function (e.g., islanding for resiliency). Finally, demonstration programs that can implement large-scale testing and validation of these control systems are needed to help instill user confidence and ensure the desired resiliency of the distributed energy assets.

Conclusion

While there is significant convergence of electric vehicles and grid storage as the grid utilizes a greater number of DER assets, the materials challenges for these systems are distinctive. While there are initial high-value-added market applications for energy storage today, there is a continuing need to reduce the cost and increase the performance to realize the full set of benefits energy storage offers. For large-scale battery systems to continue finding widespread application in the grid, they must ultimately reach costs and lifetimes comparable with other grid assets. This requires ultra-low-cost materials capable of being deployed for over 20 years. For electric vehicle applications, a different set of materials will provide the increased energy density needed to double their driving range in the future. Unlocking the full potential of U.S. researchers to address the fundamentals of energy storage, discover new materials, and rapidly translate these discoveries into practical applications is necessary to ensure that the U.S. remains a leader in energy storage technologies.

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

The CHAIRMAN. Thank you, Dr. Sprenkle.

Mr. Kathpal, welcome.

STATEMENT OF PRAVEEN KATHPAL, VICE PRESIDENT OF GLOBAL MARKET DEVELOPMENT, AES ENERGY STORAGE, AND CHAIR OF THE BOARD OF DIRECTORS, ENERGY STORAGE ASSOCIATION

Mr. KATHPAL. Thank you, Chairwoman Murkowski, Senator Cantwell and distinguished members of the Committee.

My name is Praveen Kathpal. I'm the Vice President of Market Development for AES Energy Storage, and I'm Chair of the Board of Directors of the Energy Storage Association.

AES is a Fortune 200 company, headquartered in Arlington, Virginia, and we operate in 17 countries and 15 U.S. states. We have over 10 years of experience building and operating utility-scaled, battery energy storage systems.

I'm honored to testify in front of you today on the topic of energy storage and its role in the electric power sector.

Energy storage technologies are vital for transforming our electric grid. Energy storage sits at the intersection of several trends shaping the future of electricity: the electrification of transportation, increased adoption of renewable energy, and an aging generation fleet.

As an industry, we are mobilizing around this growing opportunity. We expect the need for energy storage solutions globally to grow to ten times the size of today's market in the next five years. And as a company, AES recently announced a partnership with Siemens to create a U.S.-based joint venture that will take energy storage technology and services to customers in over 160 countries.

While there are several mature and emerging energy storage technologies, AES believes that batteries, lithium-ion batteries in particular, are best suited to serve the mainstream needs of the electricity industry because the technology is mature, it is available at low cost, and it is manufactured at a massive scale. The industry is coalescing around this technology with lithium-ion batteries representing over 95 percent of new energy storage installations in the past two years.

One of the constant challenges the electricity industry faces is capacity planning, having enough power generation capacity to meet demand during the moments when demand is the highest. The old way of solving this problem by building new gas-fired peaking power plants will lock a generation or two of electricity customers into paying for expensive plants that will outlive their usefulness. Imagine buying a rotary phone and being stuck with it for the next 30 years, even after the iPhone was available.

By 2030, the U.S. needs another 40,000 megawatts of peaking capacity which translates to spending about $45 billion building new power plants that will only be used a few hours per year.

Fortunately, there is a better way. AES is currently building what will be the largest battery facility in the world in Long Beach, California. It was selected by the utility's Southern California Edison among many other choices to provide peaking capacity because it was the most economic option.

This is a proof point that energy storage is cost-effective when it is seriously considered as an alternative and that it is available at a scale where it can truly substitute for building new power plants.

Recently, a utility in Arizona partnered with AES to use a battery when meeting peak demand in a small, remote town at half the cost it would have taken to upgrade the long power lines serving the town.

Unfortunately, energy storage does not always get a fair shake. Most existing power markets or planning and procurement mechanisms do not appropriately weigh energy storage as an alternative to building new power plants or power lines.

At the Energy Storage Association, we are working closely with the Federal Energy Regulatory Commission, utility companies, state regulators, and other stakeholders to remove structural barriers that favor legacy technologies, improving access for energy storage, and increasing competition. Smart policies that reduce these barriers will accelerate consumers benefiting from reduced costs, improved reliability and resilience and cleaner air.

Madam Chairwoman, 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 battery energy storage facilities in the U.S.

I look forward to your questions. Thank you.

[The prepared statement of Mr. Kathpal follows:]

Praveen Kathpal
Vice President
Global Market Development
AES Energy Storage

AES
we are the energy

October 3, 2017

Testimony of Praveen Kathpal, Vice President of Global Market Development of AES Energy Storage Before the U.S. Senate, Committee on Energy and Natural Resources – Full Committee Hearing to Examine Energy Storage Technologies

Thank you, Chairwoman Murkowski, Ranking Member Cantwell and Distinguished Members of the Committee. My name is Praveen Kathpal and I am Vice President of Global Market Development at AES Energy Storage and serve as Chair 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 on the topic of energy storage and its role in the electric power sector.

Background on AES Energy Storage

The AES Corporation is a Fortune 200 company headquartered in Arlington, Virginia that provides affordable, sustainable energy to U.S. states including Ohio, West Virginia and California, territories like Puerto Rico and the Virgin Islands, as well as in 16 other countries including the Dominican Republic, Chile, Brazil, the Netherlands and Northern Ireland. AES was founded more than 35 years ago with a focus on how to think differently about technology, business models and market structures to deliver innovative solutions to customers. There is no better example of our approach to innovation than in our energy storage business.

In 2007, AES Energy Storage was founded as a subsidiary of AES to commercialize applying battery technology to the electric grid. Ten years ago, battery-based energy storage on the grid was viewed as experimental, and did not exist as a business opportunity. We knew the technology and the solution would be viable, economic and profitable on its own. We designed and built the first megawatt-scale lithium-ion battery energy storage project in Indianapolis, integrating two large containers of batteries to prove that large-scale battery-based energy storage could connect to an electric grid, operate as a complete system, and respond to a remote signal to charge or discharge the battery.

Since then, AES has been recognized as the world leader in utility-scale battery energy storage systems, and we have found a business case for storage in every market we have entered.

Today, energy storage is a proven solution and is operating successfully across the country and in many overseas markets. AES continues to be a market leader and pioneer new uses of grid-scale battery energy storage. To fuel future growth, earlier this year Siemens and AES announced we will partner to create Fluence, a new, U.S.-headquartered global energy storage technology and services company that unites the scale, experience, and reach of its two parent companies to lead the next growth phase for storage – taking this vital technology to more customers in over 160 countries around the world.

Industry Context

Energy storage sits at the center of global trends shaping the electricity industry, in particular the acceleration electrification of our society and adoption of renewable and distributed energy sources.

Electricity is fundamental to everything we do, representing nearly 40 percent of U.S. end-user energy use, with transportation and industrial fuel use representing an additional 51 percent, two sectors expected to increasingly electrify in the coming years. According to the International Energy Agency, 2015 saw the number of electric vehicles on the road surpass 1 million, a major milestone, a number projected to jump to 530 million globally by 2040. As we continue to pursue the electrification of transportation and other industries, our need for clean, reliable, and affordable electricity will continue to increase.

Energy storage is also the key enabler of the integration of greater amounts of renewables into the electric power system, answering consumers' and businesses' growing demand for clean energy. Wind and solar will account for 64% of new power generating capacity added globally over the next 25 years. AES' view is that increasing access to low-cost, reliable electricity drives economic growth and furthers our mission of improving lives.

Today, our electric power system is lagging behind every other vital societal network in terms of efficiency, reliability and flexibility. IHS Markit studied four critical networks - data, travel, perishable goods and natural gas - and found that each had storage amounting to at least four days' worth of demand, and even years' worth in the case of data networks. The electric network has only 20 minutes. In the key networks IHS studied, incorporating storage across the network ensured availability, enabled greater network responsiveness, improved resiliency, and increased utilization of existing assets.

Energy storage is vital for transforming our electric grid so it can meet the needs of a rapidly changing energy landscape, as we electrify industries and increase our adoption of renewables and distributed generation. Adding storage unlocks the full potential of the electric power system, increasing access to abundant clean energy.

It also enables us to address today's power system challenges such as the United States' aging electricity infrastructure. The United States' electric power generation fleet is aging with a growing segment in need of replacement. The average generation asset has been in service 28.7 years, and 20% of capacity have been in service for 45 years or longer. In addition, the U.S. transmission and distribution grids are also aging and utilities are ramping up investments to modernize them, with spending having ballooned from $10.2 billion in 2010 to $20.1 billion five years later. Unexpected retirements of nuclear generating stations and other conventional energy infrastructure facilities have put pressure on utilities and policymakers to find other resources – in cases within months – to maintain reliability. The threat of extreme weather events only exacerbates these needs.

AES believes that battery technology, lithium-ion in particular, is uniquely suited to address these issues. Lithium-ion technology is mature with a 25-year history operating in consumer electronics and more robust industrial applications including transportation. The electric power sector is now benefiting from safety advances from electric vehicle applications, lithium-ion technology's robust global supply chain and the collective research and development investment of a global network of leading companies, many of whom have been our technology partners over the past 10 years. Rapid lithium-ion adoption has driven down costs for lithium-ion batteries dramatically, with prices having dropped 73% over the last 7 years and are projected to decline another 72% by 2030.

Business Opportunity for Battery-Based Energy Storage

Battery-based energy storage is a unique tool for the electric power sector because it manages to solve three problems at once – the need to lower costs, to lower emissions, and to improve reliability and resilience.

Energy storage lowers costs to utilities and their customers by avoiding the need to build new gas-fired peaking power plants, and by avoiding or deferring transmission and distribution infrastructure needs. It can be built in right-sized increments rather than the typical lumpy investment profile where large generation or grid assets are built in anticipation of future demand growth, the occurrence of which is increasingly uncertain. Energy storage also enables utilities and power generators to operate existing generating assets and transmission and distribution lines more efficiently. Lastly, storage is fuel-agnostic, meaning utilities can charge their facilities with the lowest-cost energy sources.

Those lowest-cost energy sources are increasingly the cleanest as well – solar and wind installations represented more than 60% of new U.S. electric generating capacity installed in 2016 and 55% of new capacity installed globally in the same year. Energy storage is increasingly seen as an enabling technology to accelerate the adoption of renewable energy.

Having enough power generation capacity to meet demand during peak time periods is a growing need for the industry, with 41 GW of peaking capacity needed nationwide by 2030, representing $45 billion in generation infrastructure investment. That total includes regions with more concentrated needs such as 5 GW in the Southwest, 4 GW in the Midwest and 10 GW in the Southeast. Investor-owned electric companies are also planning to invest approximately $56 billion on modernizing transmission and distribution infrastructure in 2017. In both cases, energy storage offers a cost-competitive, flexible resource utilities are already finding can help them meet these needs.

Commercial Cases for Utility-Scale Battery Energy Storage

Two utilities in the western U.S. are leading the way on harnessing energy storage for these key grid needs. In 2014, Southern California Edison, the largest utility in our most populous state, was facing the retirement of older natural gas-fired power plants and the unexpected retirement of a large nuclear power plant. They needed to select new sources of capacity to meet their customer's needs. SCE ran a procurement solicitation in which energy storage was compared against gas-fired generation, demand response and other resources. They awarded AES the world's first long-term contract to provide peaking capacity from a battery-based energy storage facility in Long Beach, California. This plant will be able to provide 100 MW of power for four continuous hours, directly substituting for the need to build a new gas-fired peaking plant. It was selected by SCE on an economic basis, meaning that it will provide the capacity at a lower net cost to SCE's customers than obtaining the same amount capacity from a traditional gas-fired peaking plant. SCE's decision in this case was a watershed proof point for the economics, scale, and technology maturity of battery-based energy storage to meet electric system needs.

Arizona Public Service recently partnered with AES to become one of the first electric utilities in the country to choose energy storage to avoid the need to rebuild transmission and distribution poles and wires serving a small town 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 20-mile segment of power line, APS will save its customers the cost of rebuilding those lines, which cross over difficult terrain. When not being used to serve customer demand, the battery system will provide additional benefits like voltage regulation and delivery of excess solar power, as well as the capability to add additional storage as needed, all at a similar cost. In a number of cases, energy storage enables utilities to defer or avoid entirely investments in a variety of fundamental, single-function grid assets like wires, poles, transformers and substations, and in the process, get the most value from the transmission and distribution lines they already own and use. As communities across the U.S. and elsewhere around the globe work to modernize their electric grids, utilities are beginning to recognize that energy storage enables them to think more broadly about their investment options and strategy.

Deploying battery energy storage also provides significant value on small, isolated grid systems like those in Northern Chile, where AES has deployed three arrays. They work in concert with conventional generation sources to provide grid stability, and an instant response to disturbances in the grid, such as when a large power plant or transmission line suddenly stops working. These applications are similar to how energy storage would be used in island or microgrid applications, where many energy resources need to work in concert with each other, and energy storage fills the gaps between supply and demand to ensure the reliable and efficient delivery of electricity, often avoiding the need to burn diesel fuel in generators, the predominant source of fuel in remote areas.

Battery energy storage can also be deployed in mere months to answer unexpected capacity needs. In 2016, when 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) directed Southern California investor-owned electric utilities to fast-track additional energy storage options to enhance regional energy reliability. In response, SDG&E expedited ongoing negotiations and contracted with AES Energy Storage to build two projects for a total of 37.5 MW of 4-hour duration lithium-ion battery energy storage. The larger project, a 30 MW facility built in Escondido, Calif., is currently the world's largest li-ion battery installation, and both the Escondido project and a smaller 7.5 MW installation was built in El Cajon were completed and online in eight months. Battery-based energy storage can to be deployed in months compared to the years required for traditional assets, which enabled southern California's utilities unparalleled flexibility to meet their local capacity needs.

In addition, energy storage adds resilience and can protect electric grids during extreme weather events. In the last month, Hurricanes Irma and Maria – Category 4 and 3 hurricanes on the Saffir-Simpson scale, respectively – impacted the Dominican Republic on September 7th and 21st, 2017 and stressed the local grid. AES had just deployed two 10-megawatt energy storage arrays on the Dominican grid, and as each hurricane approached the island, the grid operator requested that both systems be kept online and operational during the storm to help maintain grid stability. Conditions on the Dominican electric grid were volatile during both hurricanes as generation, transmission, and distribution networks were damaged or shut down. Both of the energy storage arrays responded as intended and helped keep the grid operating throughout the storm, even with nearly 40 and 55 percent of the Dominican Republic's generation assets forced to shut down during Hurricane Irma and Hurricane Maria, respectively.

Policy Drivers to Accelerate Energy Storage Adoption

We are seeing important state and federal policy developments that will accelerate the adoption of energy storage by lowering barriers to entry, and fostering competition between energy storage and conventional solutions to meet electricity system needs. At the federal level, we are pleased to see the proposed rulemaking from the Federal Energy Regulatory Commission that would provide fair and equal access for storage resources to wholesale power market products and services. We are also pleased to see FERC provide the direction that storage resources providing a transmission function can seek cost recovery through cost-based and market-based rate structures. We believe these are important policy initiatives at FERC that can create lasting wholesale market changes that fully value the unique capabilities that storage brings and to encourage consideration of storage use for infrastructure needs.

We also see a lot of recent momentum in state policy. States like California, Oregon and Massachusetts have instituted storage targets to accelerate adoption and realization of benefits to rate payers. Many other states including Nevada, New York, Maryland, Colorado, and Minnesota are actively pursuing storage studies of their own and considering further policy guidance for grid planners. In New Mexico, the state's Public Regulation Commission introduced a rule to include energy storage in utility integrated resource planning studies. Similarly, in Washington state, the Utilities and Transportation Commission is working on a policy statement that would encourage utilities to evaluate storage as an alternative when procuring new power capacity or upgrading their infrastructure. At AES, we believe that these types of state policies can be widely replicated to accelerate energy storage adoption across the country.

The Department of Energy has a few limited programs currently which provide technical, economic, and grid integration analysis and technical support related to energy storage. We believe that directing those analyses at real generation, transmission, or distribution problems will accelerate the adoption of storage as a cost-effective alternative to conventional electricity system investments. Expanding these programs or providing support directly to utilities, state public utility commissions, independent system operators and regional transmission organizations, reliability entities, state energy offices, and consumer advocates to analyze storage in state and regional context for generation, transmission, and distribution planning, will accelerate a more efficient level of storage investment. Areas where we currently see good analyses or programs looking at the right programs are:

- National Renewable Energy Laboratory work on the capacity value of energy storage and production cost modeling of energy storage benefits;
- Pacific Northwest National Laboratory work on energy storage in integrated resource planning; and
- Office of Energy Efficiency and Renewable Energy Analytical Support Program for State Public Utility Commissions work on the consideration of energy storage in integrated resource planning and transmission and distribution planning.

Chairwoman 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.

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The CHAIRMAN. Thank you, Mr. Kathpal and thank you for the invitation.

Mr. Moores, welcome.

STATEMENT OF SIMON MOORES, MANAGING DIRECTOR, BENCHMARK MINERAL INTELLIGENCE

Mr. MOORES. Thank you very much, Chairman Murkowski, Senator Cantwell, members of the Committee. I very much appreciate allowing myself to speak on, really, the supply chains going into these, to make these lithium-ion batteries.

My name is Simon Moores. I'm Managing Director of Benchmark Mineral Intelligence, and we spend most of our time further up from where the battery cells are actually produced. We go from the battery cell plants to the mines and everywhere in between to track data, price data, market data, numbers on the industry, what's happening in the real world.

I want to outline the states of play in the lithium-ion battery industry which, obviously, are extremely relevant for energy storage, as the applications you mentioned, which would be stationary utility storage and then also, most importantly, electric vehicles.

And so, from our perspective we're in the midst of a lithium-ion battery arms race around the world. Over the last three years we've seen these lithium-ion battery megafactories which are battery plants above one gigawatt/hour capacity rise everywhere.

It started with the Tesla Gigafactory in Nevada, but now we have 17 of them worldwide. And they continue to be popping up everywhere. The key thing is not just the size of growth that we're about to see in the lithium-ion battery industry, we expect that to go from 80 gigawatt/hours in 2016 to between 550 and 650 gigawatt/hours demand by 2025, but it's the impact this is having on the raw material supply chains.

So these are critical raw materials that go into these battery cells: lithium, graphite, cobalt and nickel. And it's important to understand these raw materials, not as commodities as we would probably be familiar in understanding minerals and metals but specialities. These are niche industries. These are tailored chemicals and materials that go into batteries, and the industries have to go from the niche to the mainstream.

So the production of these raw materials and these intermediate products have to come in order of magnitude bigger over a very short period of time, between five and seven years, in order to meet the demands from the auto companies and from the energy storage facilities as well. This means money, quite frankly.

For example, we've seen the lithium price increase four times in the last two years just because there isn't enough supply to meet demand driven by the battery sector. In this recent price spike lithium has raised about $1 billion, but really between $7 and $10 billion ago, we need it to fuel this energy storage revolution, to actually get the batteries into production, into the market. So that's a complete change in how these mineral industries operate.

Where we stand today, China is not only at the center of mass market electric vehicles, but it is at the center of all of these supply chains. It's not just where the resources lie, but it's actually the key steps, the battery grade processing steps along that supply chain, that really, we have to be focusing on trying to control, as a development and deployment of these electric vehicles, but cathode production, battery grade production and building out of new cells of capacity.

So of the megafactories mentioned, 64 percent of that capacity is being built in China. Only 13 percent so far is being built in the U.S. This could change over time as new plants get planned.

We're at the beginning of this energy storage revolution which, I think, everybody really agrees with that one. This is powered by lithium-ion batteries initially, the energy storage based on the utility storage space, should I say, will have many opportunities for other batteries, such as vanadium flow, as well.

So there are many risks and many opportunities and we're just starting, but I'm happy to answer to any questions you have and very much appreciate your time.

[The prepared statement of Mr. Moores follows:]

BENCHMARK
MINERAL
INTELLIGENCE

Tuesday 3rd October 2017

Written Testimony of Simon Moores, Managing Director, Benchmark Mineral Intelligence

For: US Senate Committee on Energy and Natural Resources Committee

Hearing: Tuesday, October 3, 2017, at 10:30 a.m. EDT in Room 366 of the Dirksen Senate Office Building in Washington, DC.

Subject: Energy storage technologies and the supply chain risks and opportunities

Thank you for inviting me to this hearing on energy storage technologies to give my independent, market-focused perspective on the opportunities and risks in the supply chains.

Energy storage is not a new concept. We store energy in our phones, laptops and power tools every day and recall and use this energy on demand.

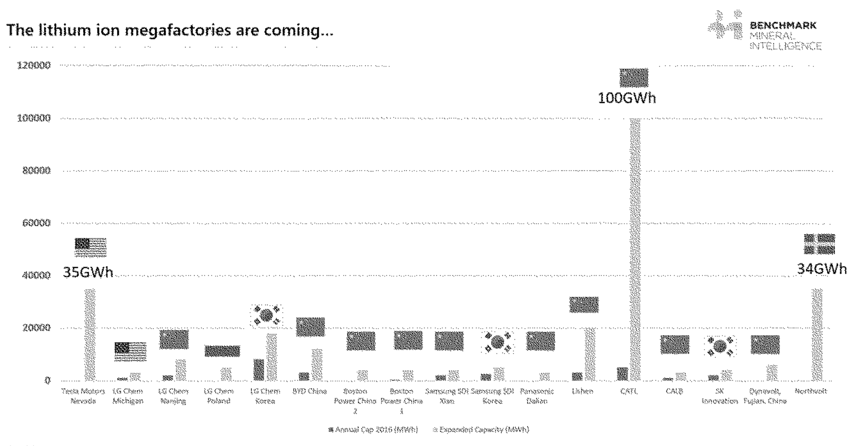
However, the widespread adoption of energy storage – most critically in our vehicles and for our homes, offices and energy distribution networks – is only just gathering pace owing to low cost, abundant lithium ion battery cells.

This trend was given impetus by rise of the lithium ion battery megafactories, a term created by Benchmark Mineral Intelligence to describe the widespread expansion of battery cell production capacity around the world. Huge battery plants are now being constructed that are an order of magnitude larger than their predecessors.

In 2014, Tesla announced their Gigafactory in Nevada with 35GWh of new cell production – the equivalent of 500,000 pure electric vehicles (EV). At the time, this was the first ever plant to have a capacity over 10GWh.

This sparked a global battery arms race that has now spread to 17 megafactories in the pipeline, 9 of which are in China and only 2 of which are based in the US. In terms of production capacity from these megafactories, China will have 64% and the US only 13%. The remainder of the planned plants are in Korea, Poland, and Sweden.

Despite this new 289GWh of capacity adding to a global lithium ion cell production of 80GWh in 2016, according to Benchmark Mineral Intelligence data, the industry is still drastically short of capacity to meet projected demand of 550-650 GWh of battery cells by 2025.



These lithium ion batteries will be targeted for use in the two largest growth markets, EV and stationary/utility storage – the two uses that underpin the energy storage revolution.

Both markets are in their infancy. However, as these applications mature over the next 10 years, the scale of application and its disruptive effect on established auto and energy industries will be unprecedented.

Pure electric vehicles – from cars to electric buses – are only entering the market place today and are all are based on the lithium ion battery technology.

Consumer choice of pure EVs, vehicles that are 100% battery powered and where a combustion engine plays no part, are beginning to become numerous. For example, 2017 saw the launch and/or rolling out of the pure EVs of Tesla's Model 3, Chevrolet's Bolt and Nissan's new LEAF.

These are the first sub-$35,000 pure EV offerings for the consumer and has ushered in the era of the semi-mass market EV.

As we approach 2020, we are seeing every single major auto manufacturer announcing aggressive pure EV plans all based on lithium ion.

Volkswagen Group, Daimler/Mercedes, Toyota, and Honda, for example, are all planning selling lithium ion powered EVs in the millions of units annually post-2020. Meanwhile, the trend in e-buses has also started to gain traction outside of China due to the efforts of California-based Proterra. These e-buses have lithium ion batteries up to ten times the capacity of EVs.

The second major energy storage trend is one of stationary / utility storage. At Benchmark, we see the utility storage sector where EVs were in 2009: a limited number of installations around the world with industry momentum increasing.

Rise of lithium ion technology

The lithium ion battery is not new technology; however, its widespread commercial use has until now been limited to portable personal technology (cell phones, laptops, power tools), hybrid vehicles and a handful of EVs.

Lithium ion technology being used is not one battery but a selection of different lithium ion types or chemistries; the ones of note are:

- Lithium Cobalt Oxide (LCO) used in portable technology
- Nickel Manganese Cobalt (NMC) used in EVs and utility storage devices
- Nickel Cobalt Aluminium (NCA) used in EVs

These chemistries are all lithium based, despite the naming convention, and the critical raw material inputs are: **lithium**, **graphite**, **cobalt** and **nickel**.

While other metals are also used in a lithium ion cell such as copper and aluminium, the speciality nature of the afore mentioned minerals and metals increases the complexity of the supply chains. It needs to be clearly understood the need to process these elements into a battery grade chemical derivative product that is tailored for each customer.

In short, we are dealing with niche, speciality chemicals and minerals rather than commodities. The biggest challenge for this handful of specialities is scaling the supply chain from the mine to the battery plant in time to meet demand from the auto manufacturers.

Lithium: a speciality, volume problem

Lithium, the highest profile input into a lithium ion battery, is sourced from Chile, Argentina (brine extraction) and Australia (traditional rock mining) and is also processed into battery grade material in the US and China.

Lithium carbonate and lithium hydroxide are the base chemicals that the battery industry seek, the industry's demand profile is increasing 10-fold in a 10-year period. Demand pressures from the battery industry have already forced prices of these chemicals up four times in the last two years and it is a rising price trend that is continuing today.

In 2016, lithium carbonate equivalent (LCE) used in lithium ion batteries equated to 75,000 tonnes. By 2025, battery demand will be 550-600,000 tonnes. A complete evolution of the industry is required to take lithium from the niche into the mainstream.

Not only does lithium need to scale its extraction capacity but also its battery grade processing capacity to meet the requirements of battery customers – an additional, specialised step.

The US has two major players in the lithium industry: Albemarle Corp and FMC Lithium are among the world's largest lithium producers sourcing predominately from Chile and Argentina brine operations, respectively. Both producers have processing capacity in North Carolina.

In terms of lithium resources, the US produces lithium chemicals from a small brine operation in Nevada. Clayton Valley is one hotspot of exploration for new lithium brine together with the Arkansas Smackover oilfield brine resource. Recent hard rock exploration for spodumene in North Carolina has also occurred in a bid to secure domestic US lithium.

Graphite: an anode processing problem

Graphite anode, the largest input into a lithium ion battery in kilograms, has a similar scaling issue. Graphite in batteries comes from two sources, naturally mined flake graphite and synthetic, man-made graphite.

In 2016, graphite anode used in lithium ion batteries equated to 100,000 tonnes. By 2025, battery demand will be 780,000 tonnes.

Natural flake graphite mining is dominated by China with 62% of global production in 2016, a position only Brazil can compete with producing 23% of the world's 650,000 tonnes. This flake graphite is then sent to spherical graphite plants – all of which are presently located in China – to be processed into anode material.

Just under 60% of the lithium ion battery industry's anode is derived from natural graphite with synthetic graphite – produced from graphitizing petroleum coke and tar pitch at very high temperatures – accounts for ~40%.

Due to lower production cost, environment and CO_2 impact issues, and ease of scaling supply, battery customers are trending towards using more natural graphite anode in their cells but are still blending with synthetic graphite. The knowhow in blending different anode materials with differing raw material signatures is a skill and intellectual property that will separate out the leaders of the pack.

While large flake graphite mines are being developed outside of China in Mozambique, Canada and the US, processing capacity to make anode material is still lagging. The US has two graphite companies seeking to mine and process flake graphite for battery grade material in Alabama and Alaska.

Cobalt & Nickel

Cobalt is the second highest profile battery raw material mainly because 64% was mined by the Democratic Republic of Congo (DRC) in 2016 and because China dominates the refining step in the supply chain with 57% of global capacity.

Headlines regarding cobalt mined illegally in DRC have dominated the cobalt discussion despite the portion of illegal material in the market being relatively low and under 10% of global supply which was 93,000 tpa in 2016.

However, illegal cobalt in the supply chain has greatly concerned end users of batteries mainly owning to the corporate social reasonability impact on their businesses.

Major end users have moved to try to eliminate illegal cobalt from the supply chain and this has opened opportunities for developers of new mines based in US (Idaho), Australia and Canada that could guarantee the provenance of their raw material.

In addition, cobalt's geological occurrence as a secondary mineral to nickel and copper means that its produced as a by-product of these metals. Only one small primary cobalt mine in the world is in operation in Morocco.

This means the fortunes of cobalt – now driven by battery demand – is still at the mercy of nickel and copper commodities which is driven by industrial demand. This is causing long term planning issues for the EV supply chain.

Cobalt used in lithium ion batteries equated to 48,000 tonnes in 2016 but this is set to increase to 180,000 tpa by 2025. While opportunities for producers' external to DRC are available, the sheer volume of new supply needed by the market means there will be no EV industry without DRC cobalt.

Most of refining to a battery grade cobalt chemical will occur in China.

Nickel – a raw material associated with cobalt but also mined individually – is growing in importance for a lithium ion battery consumer. The trend of using more nickel in a cathode and less cobalt is one that is just beginning in the commercial lithium ion space.

For NMC formulations – a chemistry that will be the number one format in the EV and utility storage space - the industry has traditionally used a 1:1:1 formula – 1-part nickel, 1-part manganese and 1-part cobalt.

However, 5:2:3, 6:2:2 and 8:1:1 nickel-rich formulations are now being introduced into lithium ion battery production lines around the world.

This is a move that will see battery grade nickel demand grow from 75,000 tpa in 2016 to anywhere between 300-400,000 tpa by 2025 depending on which chemistries take hold.

While nickel metal is a commodity that is produced in the millions of tonnes a year, the battery grade chemical material is specialist with only a handful of major producers outside of China including Japan's Sumitomo Metals Mining, which operates mines and processing plants, and Belgium's Umicore. However, the vast majority of battery grade nickel sulphate is produced in China.

Interest in the market has seen major nickel miners such as Vale, BHP Billiton, and Rio Tinto seek to enter the battery grade space. However, not all nickel deposits can produce a commercially viable battery grade material. High and lower grade class 1 nickel deposits are the most suitable yet the most capital intensive to move into production.

Competing technologies to lithium ion

Vanadium flow:

For stationary storage applications, vanadium flow batteries have been the most talked about as best-in-class for this application due to its lifetime versus lithium ion.

The challenge for this market is finding a champion for the technology with only a handful of producers competing for market share. The upfront cost of the technology is more expensive than lithium ion and despite offering a longer life time, this is discouraging some buyers.

Vanadium flow is heavily reliant on vanadium raw material that is processed into vanadium pentoxide form. Vanadium raw material output totalled 72,000 tonnes in 2016 however vanadium pentoxide used in batteries was under 3% of this demand.

Manufacturers of vanadium flow batteries will likely need to control own their own raw material source to minimise the raw material supply and price fluctuation risk which can be very disruptive to the adoption of this technology. A major positive of this technology is that vanadium can be recycled and some producers are looking at raw material leasing options for financing new battery installations.

Solid state:

Solid state batteries are the most promising successor to lithium ion but a technology that is still many years for widespread commercial adoption.

Compared to a lithium ion battery, there are no liquid components to solid state and it uses a lithium metal or silicon anode. The gains in changing the anode are the main theoretical benefits over a lithium ion battery and include higher energy density and faster charging.

Solid state technology in the commercial world has seen some activity in mid-2017. UK-based Dyson revealed it aims to enter the EV market using solid state by 2020. This was made possible because of its 2015 acquisition of Sakti 3, a US-based solid-state technology developer.

A second most recent boost was from Porsche's confirmation that it will also seek to use solid state batteries in 911 and Boxster in post-2020 production models.

Wide scale solid state battery adoption is far from guaranteed and it is yet to be seen whether solid state can work safely in real world scenarios. But the technology is widely tipped as the successor to lithium ion in a post 2030 world.

2025 Vision: Lithium ion here to stay, supply chains need to evolve

While there are huge opportunities with the energy storage revolution there are also huge risks.

The demands EV manufacturers are placing on raw material miners to chemical processors and cathode manufacturers are huge – they are being asked to increase their business footprint by 5-10 times in a 7-year period.

At present, there is little desire to share this capital and commercial risk of building new mines or expanding their business to meet this new demand.

Major auto manufacturers will eventually have to conclude that supply chain partnerships and capital investment is the only way to secure lithium, graphite, cobalt, nickel or lithium ion battery cells. But this decision-making process is slow for players outside of China and risks derailing any form of revolution in the energy storage industry.

Market momentum is now with lithium ion batteries and for this first phase of the energy storage revolution the choice has been made, certainly for EV. Over $35bn has been committed to expanding lithium ion battery plants while the lithium industry has raised $1bn to build new supply.

This investment is short by some way.

The investment into lithium ion battery capacity needs to be four times larger to satisfy demand for the mid-2020s and it needs to be 10 times larger to create a new blueprint for a post-2030 world. The lithium industry, as an example, will need raised between $7-10bn to keep pace with this new capacity and demand for EVs.

The US is very active on EV innovation mainly owing to activities by Silicon Valley based companies like Tesla and Proterra. US involvement in the raw material to cathodes to battery cell links in the supply chain is very limited however with the sway of industrial power lying in Asia Pacific countries most notably China, Japan and Korea.

This energy storage revolution is global and unstoppable. For countries and corporations, positioning themselves accordingly to take advantage of this should be of paramount importance and longer term (~10 year) decisions need to be made.

Where we stand today in 2017, China is not only at the centre of mass market EV development and deployment but also of cathode production, battery grade raw material refining, and the building out of new battery cell capacity.

Those that control raw material and chemical / cathode refining knowhow and capacity will control the lithium ion battery supply chain. And those that control the lithium ion battery supply chain will be the biggest influencers on the next generation auto and energy industries.

Simon Moores
Managing Director
Benchmark Mineral Intelligence
UK

The CHAIRMAN. Thank you, Mr. Moores. We appreciate the focus on critical minerals, and this is just the beginning of the discussion here when we are talking about what will be needed to help facilitate energy storage.

Mr. Seifarth, welcome.

STATEMENT OF JOHN SEIFARTH, HEAD OF ENGINEERING, VOITH HYDRO, INC.

Mr. SEIFARTH. Chairman Murkowski and Ranking Member Cantwell, thank you for inviting me here today to testify. I'm John Seifarth, the head of engineering at Voith Hydro in York, Pennsylvania, about two hours up the road from here. We trace our roots in the United States back 140 years. Currently, we employ around 600 employees.

Voith is a leading supplier of hydroelectric equipment and has supplied or modernized a majority of the pumped storage hydro facilities in the United States. Pumped storage hydro is the only proven form of large-scale energy storage, giving utilities and grid operators stability and reliability. Pumped storage hydro is also essential for deployment of additional renewable energy sources, such as wind and solar.

Currently, 97 percent of utility-scale energy storage in the United States is from pumped storage hydro. It represents nearly 22 gigawatts, or 20 percent, of our installed hydroelectric capacity.

How does it work? When energy demand is low, water is pumped to a higher elevation reservoir. The upper reservoir stores this water for points in time when energy demand increases and the water is simply released back through the turbines to generate electricity. It does this with an overall efficiency of 80 percent, surpassing other storage technologies.

Pumped storage has evolved from conventional pumped storage which reacts to grid demands in minutes to current, state-of-the-art pumped storage facilities that react to the grid demands in milliseconds.

Unfortunately, pumped storage is often not valued properly in the market. Like other hydropower technologies, pumped storage projects are subject to an incredibly long licensing process, include the development costs and it becomes difficult for utilities to pursue pumped storage projects despite their obvious benefits.

With respect to licensing, Committee members deserve credit for their work on the Energy Policy Modernization Act of 2016. That bill sought to streamline the hydropower licensing process, including designating the Federal Energy Regulatory Commission (FERC) as the lead agency throughout the process. It would also give FERC the authority to set a schedule for this cumbersome process while maintaining environmental safeguards.

I am pleased to see Chairman Murkowski and Ranking Member Cantwell reintroduce similar legislation in the Energy and Natural Resources Act of 2017. That bill contains Ranking Member Cantwell's proposal for a $50 million annual energy storage research, development, and demonstration program. The bill also requires FERC to establish an expedited review of the licensing process and market compensation barriers for new closed-loop and low-impact pumped storage projects.

Pumped storage R&D, through DOE, would fund the development of new turbine designs and small modular pumped storage projects and quantify the gaps in the policy evaluation of ancillary services and grid reliability. Complete and accurate valuation is perhaps the biggest challenge and opportunity for pumped storage hydro. If pumped storage isn't valued correctly and accurately in the market, it simply won't get built.

The tax code is another solution. Congress should adopt an extension of the hydropower investment tax credit which expired in 2015. An investment tax credit for new pumped storage projects should also be considered.

As a point of reference, our European colleagues are already building new and modernizing existing pumped storage facilities with cutting edge equipment that reacts to grid faults in milliseconds. This is required to manage their increase in wind and solar energy.

Our task is clear. Pumped storage deployment is essential for the expansion of renewables. The 2016 DOE Hydropower Vision Report determined that pumped storage hydropower has the potential to grow by 36 gigawatts, but that can't happen without supporting policy. And without these policy changes, we also lose out on the tremendous job and economic benefits created by pumped storage hydropower across the country.

Thank you and I look forward to your questions.

[The prepared statement of Mr. Seifarth follows:]

Testimony of John Seifarth
Head of Engineering, Voith Hydro, Inc.

Statement for the Record

Before the U.S. Senate Committee on Energy and Natural Resources

Full Committee Hearing to Examine Energy Storage Technologies

October 3, 2017

Chairman Murkowski, Ranking Member Cantwell, and members of the Senate Energy and Natural Resources Committee: thank you for inviting me here today to testify on the tremendous value and potential of pumped storage hydropower.

I am the Head of Engineering at Voith Hydro, located in York, Pennsylvania. We are a 150-year old company, and we trace our roots in the United States back 140 years. Voith Hydro employs nearly 600 people in the United States, and all Voith divisions throughout the world employ nearly 20,000.

Both domestically and across the globe, we are a leading supplier of hydroelectric turbines, generators, automation, and other equipment. This is particularly true for pumped storage hydro generating equipment, where Voith has either supplied or modernized major generating components (i.e., pump/turbine or generator/motor) for about half of the pumped storage hydro facilities in the United States. These include projects like Bath County in Virginia, Raccoon Mountain in Tennessee, Castaic in California, Bad Creek in South Carolina, and Muddy Run in Pennsylvania. Voith Hydro has played a constant role in advancing the technology harnessing the world's largest developed source of renewable energy.

I am particularly excited about today's topic because pumped storage hydro is a highly-advanced – and in many ways, underutilized – form of energy. It is also the only proven form of large-scale energy storage, which gives utilities and grid operators the stability and reliability they need to deliver a constant flow of energy to their customers. Pumped storage hydro is also essential for the further deployment of other renewable energy resources such as wind and solar. Pumped storage hydro helps balance energy grids that are becoming increasingly reliant on more intermittent sources of energy.

According to the Department of Energy's 2016 Hydropower Vision Report, current pumped storage capacity in the United States is just under 22 gigawatts, and comprises 97% of utility-scale energy storage in the United States. Even though there are only 42 pumped storage facilities in the U.S. (compared to nearly 2,200 non-pumped storage hydropower plants), pumped storage accounts for over 20% of the installed hydro capacity in the United States. That statistic alone shows the massive storage capacity that pumped storage hydro offers our nation to help with the transition to a more renewable energy-based economy.

The concept of pumped storage hydro is simple. During times when demand for energy is low, such as the middle of the night, water is pumped up to a higher elevation reservoir. This upper reservoir "stores" the energy used to pump the water up to the reservoir. That water remains there until demand for energy increases, at which point the water is released back through the turbines to generate energy. Pumped storage converts the potential energy of falling water into electricity that is deployed across the country, and it accomplishes this service with an overall efficiency of roughly 80%. Other energy storage methods cannot match this level of efficiency and sustainability.

The technology, engineering, and construction that goes into pumped storage is anything but simple. Each pumped storage unit is designed with the specific grid it is serving in mind to ensure the energy demand is met. That means other forms of energy serving the grid – such as nuclear, coal, natural gas, and other renewables – significantly affect the engineering and design of a pumped storage facility.

Though pumped storage is not a new technology, it is also not static. Over the last 100 years since Voith's first pumped storage unit was delivered, the technology has constantly improved. The evolution of pumped storage has gone from conventional pumped storage, which reacts to grid demands in minutes, to advanced conventional pumped storage, which reacts to the grid demands in seconds, to the current state-of-the-art variable speed, ternary, and full power frequency converter pumped storage facilities, which react to the grid demands in milliseconds.

Although pumped storage facilities are built to last for decades, the longer the facility has been operational, the less equipped it is with the most up-to-date technology that would allow these facilities to better account for a rapidly changing energy supply. These plants can also fall behind modern standards for efficiency; in those cases, operators are not extracting the full benefit of a pumped storage. A streamlined and robust licensing (and relicensing) process will make a huge impact to the utility grid value of these pumped storage facilities.

Like conventional and small hydropower technologies, pumped storage projects can take an incredibly long time to get licensed and ultimately built. The inherent cost of these large infrastructure projects, coupled with a licensing process that can take a decade or longer means many developers and utilities do not pursue pumped storage projects that would otherwise provide substantial benefits to their energy portfolios and, ultimately, the reliability of our nation's power grid.

With respect to licensing, I would like to thank Committee members for your work on the Energy Policy Modernization Act of 2016. That bill included provisions long-sought by our industry that would streamline the licensing process for hydropower, including designating the Federal Energy Regulatory Commission (FERC) as the lead agency throughout the licensing process. It would also give FERC the authority to set a schedule for this often cumbersome and timely process. Notably, this improved process would keep in place environmental safeguards, but ensure projects do not languish and give their developers have some degree of regulatory certainty during the process.

Given that bill's fate at the end of last Congress, I am pleased to see Chairman Murkowski and Ranking Member Cantwell reintroduce similar legislation in the Energy and Natural Resources Act of 2017. Of particular interest to this hearing, that legislation contains Ranking Member Cantwell's proposal for a $50 million annual grid storage research, development, and demonstration program. That's a good and important first step.

Further, the Energy and Natural Resources Act requires FERC to establish an expedited review of the licensing process for new closed-loop pumped storage projects, identify project development and market compensation barriers for pumped storage, and encourages FERC to provide greater certainty with respect to the licensing timeline for low-impact pumped storage projects.

I hope both the Senate and the House reconsider this legislation and its provisions become law.

Outside of the regulatory landscape, perhaps the biggest challenge for pumped storage hydro is proper and accurate valuation. Nearly everyone agrees that energy storage is a priority, but there is considerably less agreement in how to account for that value in a way that has a true market impact. The lack of proper valuation with necessary context to the role storage plays on the energy grid is another hindrance to the development and deployment of pumped storage hydropower.

One way to solve this problem is through the tax code. Capacity additions, performance improvements, and life extension to existing pumped storage projects qualify under federal tax incentives for hydropower. However, these incentives expired in 2015. At a minimum, Congress should adopt an extension of the hydropower Investment Tax Credit (ITC), similar to the solar industry. Additionally, an investment tax credit for new pumped storage projects should also be adopted, along with eligibility for the Clean Renewable Energy Bonds (CREBs) program. I hope these provisions are considered in the tax reform effort currently being developed in Congress.

In addition, the research capabilities at the Department of Energy should not be ignored. The DOE's Water Power program needs continued funding. Pumped storage R&D support would fund activities such as the development, testing, and deployment of new turbine designs; the development of new small modular pumped storage projects; and the identification and quantification of the gaps in valuation of ancillary services and grid reliability in various federal and state policy.

In its recent Electricity Markets and Reliability Report (better known as the Grid Study), DOE acknowledged many of the issues outlined in my testimony. With respect to hydropower, the report said, "Encourage FERC to revisit the current licensing and relicensing process and minimize regulatory burden, particularly for small projects and pumped storage." It also commented on the need for storage, determining "A grid with higher levels of [variable renewable energy] and more dynamic customer loads will need more of the services that energy storage can provide by acting on both the supply and demand side, including energy, capacity, energy management, backup power, load leveling, and [essential reliability services], over periods from seconds to hours or days."

Pumped storage projects are proven solutions for each of the energy service concerns identified in the Grid Study. I encourage this committee to work with DOE and stakeholders to address these well-established challenges.

Our European colleagues are already facing the reality of an energy grid comprised of mainly intermittent power sources. The older conventional storage facilities do not react fast enough to secure a reliable grid. As a result, they are rapidly advancing the deployment of cutting-edge equipment that reacts to grid faults in milliseconds (such as variable speed and ternary pumped storage units coupled with full power frequency converters). Many of these projects involve modernization and rehabilitation of existing conventional pumped storage facilities; however, several new facilities are also being built, particularly in areas prone to grid reliability issues.

In the United States, the challenge is clear. If we want more wind and solar power on our grid, or any other new form of energy, pumped storage *must* be expanded. In that same 2016 Hydropower Vision report I referenced earlier in my testimony, the DOE determined that pumped storage hydropower has the potential to grow by 36 gigawatts. In fact, pumped storage accounted for nearly 75% of the total hydropower increase envisioned by the report. But that can't happen without some of the policy changes I've outlined.

While I know this committee is primarily tasked with ensuring our country's energy needs are met and natural resources are utilized appropriately, I'd be remiss if I didn't at least mention the economic impacts of pumped storage. As with any large-scale infrastructure project, modernizing and retrofitting, and increasing the supply of pumped storage hydropower will be a serious economic boom, both in towns like York, Pennsylvania, and the communities where pumped storage projects are located. These projects benefit the people engineering the turbines and building the infrastructure, and the people who work for the over 2,000 companies in the national hydropower supply chain.

Thank you again for the opportunity to share my views, and I look forward to taking your questions.

Challenges and Opportunities For New Pumped Storage Development

A White Paper Developed by NHA's Pumped Storage Development Council

1.0 EXECUTIVE SUMMARY

An essential attribute of our nation's electric power system is grid reliability - ensuring that electric generation matches electric demand in real-time. The primary challenge in ensuring reliability is that electricity has no shelf life - it must be generated when needed - and electricity demand continually changes, especially between daytime periods of peak demand and night-time periods of low demand.

Electric transmission grid operators have long met this challenge on a real-time basis with a limited number of generation technologies - specifically hydropower and gas-fired combustion turbines - that have the ability to start up quickly and/or vary their electric output as the demand changes.

However, these solutions may not be enough as we move into a world with far greater amounts of renewable energy on the grid. In that new reality, reliable, affordable and grid-scale storage of energy must be on the table. Fortunately, a technology exists that has been providing grid-scale energy storage at highly affordable prices for decades: hydropower pumped storage. Indeed, for the foreseeable future hydropower pumped storage stands alone as the only commercially proven technology available for grid-scale energy storage.

> ***Hydropower pumped storage is the only commercially proven technology available for grid-scale energy storage.***

The last decade has seen tremendous growth of wind and solar generation in response to favorable tax incentives and other policies. While increasing the amount of renewables on the grid is a good thing, the variability of wind and solar generation increase the need for energy storage.

Developing additional hydropower pumped storage, particularly in areas with recently increased wind and solar capacity, would significantly improve grid reliability while reducing the need for construction of additional fossil-fueled generation. Grid scale storage could also reduce the amount of new transmission required to support many states' goals of 20-33% renewable generation by the year 2020.

> ***Developing additional hydropower pumped storage, particularly in areas with recently increased wind and solar capacity, would significantly improve grid reliability while reducing the need for construction of additional fossil-fueled generation.***

Pumped storage hydropower has a long history of successful development in the U.S. and around the world. Energy storage has been a part of the U.S. electric industry since the first hydropower projects, primarily through the flexible storage inherent in reservoirs. In the U.S., there are 40 existing pumped storage projects providing over 22,000 MWs of storage, with largest projects in Virginia, Michigan and California (Bath County, Ludington and Helms, respectively). Additionally, there currently are 51,310 MWs representing over 60 pumped storage projects in the FERC queue for licensing and permitting. Globally, there are approximately 270 pumped storage plants either operating or under construction, representing a combined generating capacity of over 127,000 megawatts (MW). As a proven technology, it been shown to be cost effective, highly efficient, and operationally flexible. This grid scale storage technology has been used extensively to both store and redistribute electricity from periods of excess supply to periods of peak demand and provide grid reliability services in generation mode. . Similar to the U.S., European energy policy is also focused on adding clean, renewable energy to the grid. And the significant amounts of wind and solar being brought on-line is the motivating force that is driving new pumped storage development noted above.

The National Hydropower Association (NHA) believes that expanding deployment of hydropower pumped storage energy storage is a proven, affordable means of supporting greater grid reliability and bringing clean and affordable energy to more areas of the country.

> ***Hydropower pumped storage is "astoundingly efficient…In this future world where we want renewables to get 20%, 30%, or 50% of our electricity generation, you need pumped hydro storage. It's an incredible opportunity and it's actually the lowest cost clean energy option." – U.S. Energy Secretary Dr. Steven Chu, September 2009***

While benefits of expanding pumped storage capacity are clear, current market structures and regulatory frameworks do not present an effective means of achieving this goal. Policy changes are needed to support the timely development of additional grid-scale energy storage. To this end, NHA has developed a series of recommendations to guide the energy industry and policy makers. NHA's key policy recommendations are presented in detail in Section 4 of this paper, and include:

- Create market products that allow flexible resources to provide services that help meet electric grid requirements, including very fast responding systems that provide critical capacity during key energy need periods.
- Level the policy playing field for pumped storage hydropower with other storage technologies to encourage the development and deployment of all energy storage technologies.
- Recognize the regional differences within the U.S. generation portfolio and the unique roles energy storage technologies play in different regions.
- Recognize the energy security role pumped storage hydropower plays in the domestic electric grid.

- Establish an alternative, streamlined licensing process for low-impact pumped storage hydropower, such as off-channel or closed-loop projects.
- Improve integration of Federal and state agencies into the early-stage licensing processes for pumped storage hydropower.
- Facilitate an energy market structure where transmission providers benefit from long-term agreements with energy storage facility developers.

This paper includes two supporting appendices that present additional detail on historic and current trends in pumped storage hydropower development (Appendix A) and provide a brief summary of advancements in equipment technology (Appendix B) which may provide further benefits to the integration of additional variable renewable energy resources.

1.1 INTRODUCTION - THE NEED FOR PUMPED STORAGE

Pumped Storage: An Overview

Pumped storage hydropower is a modified use of conventional hydropower technology to store and manage energy or electricity[1]. As shown on Figure 1, pumped storage projects store electricity by moving water between an upper and lower reservoir.[2] Electric energy is converted to potential energy and stored in the form of water at an upper elevation. Pumping the water uphill for temporary storage "recharges the battery" and, during periods of high electricity demand, the stored water is released back through the turbines and converted back to electricity like a conventional hydropower station. In fact, at many existing pumped storage projects, the pump-turbines are already being used to meet increased transmission system demands for reliability and system reserves. Current pumped storage round-trip or cycle energy efficiencies exceed 80%, comparing favorably to other energy storage technologies and thermal technologies[3]. This effectively shifts, stores, and reuses energy generated until there is the corresponding demand for system reserves and variable energy integration. This shifting can also occur to avoid transmission congestion periods, to help more efficiently manage the transmission grid, and to avoid potential interruptions to energy supply. New adjustable-speed technology also allows pumped storage to provide fast ramping, both up and down, and frequency regulation services in both the generation and pump modes. This is important because many of the renewable energy resources being developed (e.g., wind and solar) are generated at times of low demand and off-peak energy demand periods are still being met with fossil fuel resources, often at inefficient performance levels that increase the release of greenhouse gas emissions.

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[1] "Pumped storage" as it is used in this document is primarily for the purpose of storing electricity, although "energy storage" is a commonly used term throughout. "Energy storage" is commonly differentiated to primarily include thermal, natural gas and various forms of chemical processes. In pumped storage hydropower, previously generated electricity is converted to potential energy when pumped uphill and stored in the form of water at an upper elevation (reservoir), where it later flows downhill to a lower reservoir through turbine and converted back to electricity.

[2] Pumped storage projects generally involve an upper and lower reservoir; however, there are other project design concepts under consideration that would locate one or both reservoirs below ground (sub-surface) to take advantage of abandoned mines, caverns, or other storage reservoirs. These types of projects could be attractive due to their perceived site availability and their potential for reduced environmental impacts.

[3] Round trip or cycle efficiency can vary significantly for different energy storage technologies, depending on application (battery, flywheel, etc.), number of cycles, and duration of usage. In general, distributed energy storage technologies (flywheels, batteries) have cycle efficiency ranging from 60%-95%, and bulk energy storage systems (pumped hydro and CAES) ranging from 70% to 85%. As a comparison, simple cycle and combined cycle gas turbine plants have cycle efficiency ranging from 30%-60% (Alstom Power Data Base).

Additional information related the historical development, operational characteristics, and worldwide function of pumped storage is provided in Appendix A.

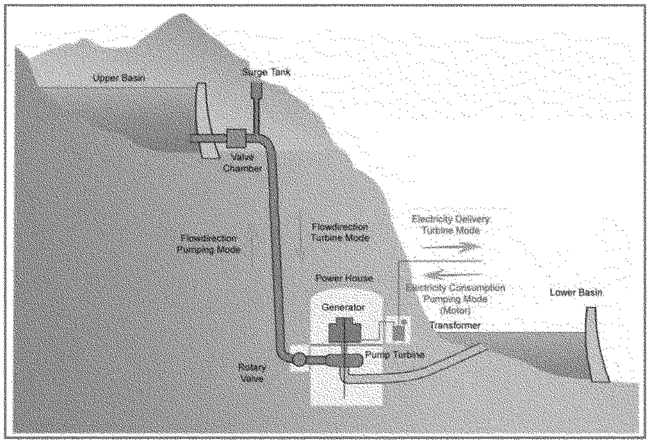

Figure 1: **Typical Pumped Storage Plant Arrangement (Source: Alstom Power).**

Hydropower, including pumped storage, is critical to the national economy and the overall energy reliability because it is:

- The least expensive source of electricity, not requiring fossil fuel for generation;
- An emission-free renewable source;
- Able to shift loads to provide peaking power without requiring ramp-up time like combustion technologies; and
- Often designated as a "black start" source, able to restore network interconnections if a power blackout occurs.

Source: U.S. Department of Energy and Homeland Security – Dams and Energy Sectors Interdependency Study, September 2011.

The Need for Bulk Storage

During the last decade, variable renewable energy projects (primarily wind and solar-based technologies) have gained strong momentum in response to favorable tax incentives and the social preference for renewable energy without the potentially harmful environmental impacts of carbon-based generation. However, these resources increase the need for system reserves (i.e., firming resources) to satisfy existing grid requirements and the variable nature of many renewable energy technologies. These firming resources typically include coal-fired and natural gas plants, and the existing fleet of hydropower facilities. As the capacity of available firming resources reaches the limit to support variable renewable energy resources, the U.S. electric industry has commonly turned to construction of new natural gas plants because of their short permitting process and relatively low fuel cost. The increased fleet of natural gas peaking plants can result in excess or underutilized facility capacity. This condition is frequently inefficient and can result in costly idling of these resources during low consumer demand periods or periods of peak variable renewable energy generation. More critically, these firming resources must be operated at an inefficient partial load to provide that system flexibility, even when the power is not needed. In some areas of the Pacific Northwest or Southwest, the impact of having excess amounts of electricity is becoming a significant concern for electric grid operations and these conditions will only be exacerbated by continued development of variable renewable energy. Bulk storage, such as pumped storage hydropower, could significantly reduce the need for conventional reserve generation capacity, support the development and optimal integration of renewable energy resources, and reduce the amount of new transmission required to support the goal of 20-33% renewable generation in these regions by the year 2020.

Since deregulation of the electric industry, there is no regulatory mechanism or market price incentive for the effective integration of new generation, energy storage, and transmission (Miller, 2010). Yet these are three components of a reliable energy generation and transmission system that require coordinated, long-term planning. In addition, in certain market regions, large amounts of variable renewable energy generation are creating new challenges for the overall transmission system and its grid operators. Bulk energy storage could alleviate some of these difficulties and promote the development of new variable energy because it would be able to shift renewable energy generated during low demand periods to higher demand periods, thereby maximizing the value of these projects. The fast ramping capability of current technology can also manage hourly and intra-hour changes in generation. Because bulk energy storage can be used to optimize the transmission grid and reduce the amount of new transmission required, NHA believes it should be included in regional transmission planning processes under Federal Energy Regulatory Commission (FERC) Order 1000[4].

4 FERC Order 1000: *Transmission Planning and Cost Allocation by Transmission Owning and Operating Public Utilities* (July 21, 2011).

Renewable Energy Growth – Driving the Need for Energy Storage

In 2010, renewable energy generation accounted for 8% of the total energy supply in the U.S. (Energy Information Administration [EIA], April 2011). Hydropower, biomass, and geothermal energy are capable of providing predictable, consistent generation; however, wind and solar generation, while less variable with adequate geographic diversity, can present new challenges for U.S. grid reliability and stability. The power output for these plants can fluctuate widely as weather patterns change and, while the changing weather patterns may be well understood, the magnitude of renewable energy generation ramps (in particular, when not in correlation with changing load) can be challenging to grid operators when renewable energy resources are a large component of their generation portfolio. This variable output can lead to frequency and voltage fluctuations, which adversely affect grid stability. In geographic regions without a significant hydroelectric generation base, this variability is most commonly managed with fossil fuel-based thermal generation.

According to the American Wind Energy Association (AWEA), over 1,100 megawatts (MW) of wind power capacity were installed during the first quarter of 2011 – more than double the capacity installed in the first quarter of 2010 (RenewableEnergyWorld.com, 2011). The U.S. wind industry had 40,181 MW of wind power capacity installed at the end of 2010, which produced 2.3% of the electricity in the U.S. (increased from 1.8% in 2009). The U.S. wind industry has added over 35% of all new generating capacity over the past four years, second only to natural gas generation (EIA, April 2011). The EIA also projects that non-hydropower renewable energy generation sources will increase from approximately 47,000 MW in 2009 to over 100,000 MW in 2035, with the majority of this projected increase attributed to wind-powered generation (EIA, April 2011). NHA fully acknowledges the significant benefits that wind and other renewable energy sources can provide with regards to domestic energy security; however, without adequate system planning, including bulk storage, the integration challenges of more renewable energy resources are likely to be in conflict with electric grid operators' goals to provide stable, secure, and reliable energy to consumers.

> *"... when the wind generation on BPA's system is operating at full capacity (which typically occurs at night), wind output alone approaches the total load within BPA's balancing area....The result has been increasing generation-following charges and major curtailments of wind generation. The BPA experience foreshadows what will happen around the country as balancing authorities tackle the challenge of integrating wind and solar. Even more serious, regional transmission organizations such as the Midwest Independent System Operator and the Southwest Power Pool have begun imposing major curtailments on the output of wind generators due to transmission congestion and minimum generation events, situations that are only likely to worsen if the penetration of intermittent renewable energy resources increases... If we are to achieve renewable energy goals, the Federal government needs to clear away barriers to grid-scale energy storage that the Federal government itself has raised."*
>
> *Source: Eagle Crest Energy - White Paper on Removing Federal Barriers to Grid-Scale Energy Storage, November 2011.*

1.2 2.0 MAJOR CHALLENGES TO PUMPED STORAGE IN THE U.S.

Environmental Issues for Pumped Storage Siting

Significant environmental misconceptions face many pumped storage developers today. In the past, almost all of the operating pumped storage projects required the construction of at least one dam along main stem rivers, altering the ecology of the river system. Enhanced awareness of the impacts from construction of large dams and storage reservoirs on existing river systems generally precludes further consideration of these large projects, or developers work directly with the environmental community to try to reduce or mitigate project impacts. The majority of existing pumped storage project owners (typically investor/publically owned utilities or the Federal government) has attempted to address these impacts through significant post-construction efforts to improve habitat or provide project-specific mitigation measures. In today's pumped storage development community, project proponents attempt to minimize these issues by focusing on new project sites where proposed construction would have minimal environmental impacts, rather than attempting post-construction mitigation measures.

A relatively new approach for developing pumped storage projects is to locate the reservoirs in areas that are physically separated from existing river systems. These projects are termed "closed-loop" pumped storage, because they present minimal to no impact to existing river systems. After the initial filling of the reservoirs, the only additional water requirement is minimal operational make-up water required to offset evaporation or seepage losses. By avoiding existing complex aquatic systems entirely, these types of projects have the potential to greatly reduce the most significant aquatic impacts associated with project development. In addition, because closed-loop pumped storage systems do not need to be located near an existing river system or body of water, with the right topographical features, they can be located where needed to support the grid.

Regulatory Treatment of Pumped Storage

Another significant challenge facing pumped storage project developers is the regulatory timeline for development of new projects. Under Section 10(a) of the U.S. Federal Power Act, any non-Federal pumped storage developer must obtain a FERC license, as well as multiple other state or Federal permits. Under the current FERC licensing process, obtaining a new project license to construct can take three to five years, or even longer before the developer will have the authority to begin project construction. There is currently no alternative licensing approach for low-impact or closed-loop sites to shorten this time frame. In addition, a three- to five-year construction period is common for most large projects; furthermore, environmentally benign projects being developed to support renewable energy integration could take six to 10 years or longer to construct. Very few financial institutions are willing to finance these types of long-lead projects through the licensing timeframe. NHA and the hydropower industry are continuing to work closely with the FERC to streamline the licensing process for those projects with obvious minimal environmental constraints, especially when many new projects can help support the development and integration of additional renewable energy resources.

At the IQPC 6th Annual Energy Storage Summit meeting in San Francisco on March 27, 2012 FERC Commissioner John Norris said storage should and probably will play a wider role in policy and planning. Policy and regulatory initiatives and the technology itself need to be lined up, but "the time for storage to be integrated in plans is now."

Commissioner John Norris acknowledged that the lack of any national policy makes life more difficult for storage advocates, most clearly in navigating the vast differences between operating in areas with organized markets and regions without them.

"All the reports I read walk up to the same line and then stop: Is it transmission, distribution, generation or all three? The answer is yes," Norris said. "We have to find ways to compensate storage for all its benefits." Generally speaking, FERC's goal is to remove barriers to the development of storage projects that would provide benefits to consumers, he said. "I can't speak for the other commissioners, but I think you can read the tea leaves," he said. "Our rulings indicate a unified commission that is supportive of storage."

Source: K. Bleskan, SNL Financial LC, "FERC's Norris Promises Special Attention to Storage", March 28, 2012.

Existing Market Rules and Impact on Energy Storage Value

In today's electric market, pumped storage has the potential to bring added value through ancillary services, beyond time-shift of energy delivery. However, a lack of a national energy policy may lead to changing independent system operators (ISO) market rules and product definitions that may have a significant impact on the value of ancillary services, including those related to energy storage. FERC Orders 890 and 719 required ISOs to modify their tariffs and market rules so all non-generating resources, such as demand response and energy storage, can fully participate in established markets. However, these are typically real-time or day-ahead markets and there are no long-term value streams where a bulk storage project can attract investors seeking revenue certainty through long-term power purchase agreements or defined value streams (EPRI, 2010).

Struggle over Generation or Transmission - Concept of Storage as a New Asset Class

While the previous sections of this paper focused on generation sources and how pumped storage fits into the energy market, energy storage technologies have the ability to provide components of transmission assets along with their ability to supply ancillary services and alleviate congestion by absorbing excess generation. Market rules generally prohibit transmission assets from participating in wholesale energy and ancillary service markets to maintain the independence of grid operators and avoid the potential for market manipulation, whether real or perceived. Furthermore, FERC requires market power studies to be performed when third parties provide ancillary services at market-based rates to transmission providers (i.e. *Avista Restriction*[5]). In addition, the policy prohibits sales of ancillary services by a third-party supplier to a public utility that is purchasing ancillary services to satisfy its own obligations to customers under its open access transmission tariff. This restriction removes one of the largest potential markets for bulk-scale storage. This clear distinction between transmission and generation assets is problematic for energy storage (EPRI, 2010), because pumped storage or other energy storage projects have components of both transmission and generation.

Some industry participants are interested in presenting bulk energy storage as a new asset class that could be similar to the existing gas storage asset class recognized by the FERC. NHA supports further evaluation of this issue.

FERC Order 1000 introduces robust regional planning into the transmission process. It also mandates coordination among neighboring transmission planning regions with their interconnection. Because Order 1000 establishes requirements for reforming transmission cost allocation processes, it creates an opening for energy storage to be included in the transmission planning process and in changes in regional and interregional cost allocation processes. If, as a result of the transmission planning process, a project is accepted into a regional plan it would therefore appear to meet the threshold requirements of Section 219 of the Federal Power Act, making it eligible for incentive rate treatment. In addition, having storage included in transmission planning could enable a developer seeking to sell a variety of storage-only services to be deemed eligible for long-term incentive rate recovery, similar to transmission assets. Energy storage does not generate energy, but only stores and returns it to the market when needed, so there would be no potential of "over recovery" by having the facility used as both transmission and generation.

Lacking an energy storage asset class, some storage providers have applied to the FERC or their respective ISOs to be considered as a transmission asset, with rate-based cost recovery included in transmission tariffs or grid charges. For example, proponents have argued that battery energy storage serves a reliability function similar to substation equipment, such as large electricity capacitors, which are used in many wholesale transmission system facilities (FERC, 2009). The FERC has approved the inclusion of storage as a transmission asset (Isser, 2010), but has been careful to limit its rulings to the specific assets in question, based on the reliability and operational benefits they provide to the grid.[6] However, these limited decisions on small storage facilities do not address the issue of grid-scale energy storage technologies such as pumped storage. The possibility of establishing bulk energy storage as a new asset class are being discussed with the FERC and other regulatory bodies, and will evolve along with market needs and preferences.

[5] *Avista Corp. Rehearing Order*, 89 FERC ¶ 61,136 at 61,391 (1999).
[6] For the WGD proposal, all FERC incentives were approved on the condition that CAISO approve the projects as part of its transmission planning process (EPRI, 2010).

1.3 OTHER FACTORS SUPPORTING THE CASE FOR PUMPED STORAGE

Energy Storage Technology Cost Comparison

Modern pumped storage hydropower project costs can vary based on site-specific conditions such as site geology, water availability, access to the transmission grid, and overall construction cost. A feasible project site would include an approximate cost estimate range from $1,500/kilowatt (kW) to $2,500/kW, based on an estimated 1,000 MW sized project. A smaller project typically does not have the same economies of scale and could result in higher unit costs (in $/kW) than a large project. These costs are representative for all project aspects except transmission interconnection charges, which can range from very minor charges to several hundred million dollars, based on factors such as existing line capacity or size and distance of new lines. According to an Electric Power Research Institute (EPRI) report (EPRI, 2010), the levelized cost of pumped storage and compressed air energy storage (CAES), the only other large grid-scale energy storage technology, represent the lowest cost forms of energy storage technologies.

New Technology Developments Affecting Current and Future Pumped Storage Projects

Pumped storage technology has advanced significantly since its original introduction and now includes improved efficiencies with modern reversible pump-turbines, adjustable-speed pumped turbines[7], new equipment controls such as static frequency converters and generator insulation systems, as well as improved underground tunneling construction methods and design capabilities. Overall, the pumping/generating cycle efficiency has increased pump-turbine generator efficiency by as much as 5% in the last 25 years, resulting in energy conversion or cycle efficiencies greater than 80% (MWH, 2009).

Globally, there are approximately 270 pumped storage plants either operating or under construction, representing a combined generating capacity of over 127,000 MW. Of these total installations, 36 units consist of adjustable-speed machines, 17 of which are currently in operation (totaling 3,569 MW) and 19 of which are under construction (totaling 4,558 MW). Adjustable -speed pump-turbines have been used since the early 1990s in Japan and the late 1990s in Europe. A main reason that adjustable speed pumped storage was developed in Japan in the early 1990's was the realization that significant quantities of oil burned in combustion turbines could be reduced by shifting the responsibility for regulation to pumped storage plants. Another advantage of adjustable-speed units is the increase in overall unit efficiency due to the fact that the turbine can be operated at its peak efficiency point under all head conditions, resulting in increased energy generated on the order of 3% annually. The current U.S. fleet of operating (single-

[7] In Japan the use of the term "variable speed" is common, where in Europe and other parts of the world, the term "adjustable speed" is often used. See Appendix B for additional information.

speed[8]) pumped storage plants does not provide regulation in the pump mode because the pumping power is "fixed" – a project must pump in "blocks" of power. The number and magnitude of blocks is dependent on the number and size of the plant's units. However, adjustable-speed pumped storage units, while similar to single speed units in most aspects, are able to modulate input pumping power for each unit and provide significant quantities of frequency regulation. This can be very attractive to project owners since regulation service prices are a valuable ancillary service.

Another expanded new key ancillary service opportunity in the U.S. is the added need for load following and regulation (generally known as system reserves) at night to accommodate variable renewable energy inputs. In particular, the need for system reserves at night is increasing to ensure adequate grid stability with higher percentages of variable renewable energy generation, including the demand for energy absorption capabilities during periods of high wind generation during low load (demand) periods. In addition to energy absorption needs, with the increased amounts of variable renewable energy being supplied at night while load is decreasing, there is a complimentary greater need for load following and regulation services to accommodate the greater changes to net load on the system. Thermal generating units typically operate at minimum load during low energy demand periods such as late night or early morning, and wind is commonly increasing output during these periods, creating a greater need for a physical asset to provide system reserves to manage the resulting energy imbalance (Kirby et al., 2009). Additional discussion of the value of adjustable-speed technology is presented in Appendix B.

Market Drivers behind International Pumped Storage Development

Globally, there are currently over 60 pumped storage projects under construction, with the majority of these projects being constructed in Europe, India, China, and Japan. The momentum behind this growth is founded in energy policies that balance the growth of intermittent renewable energy generation with energy storage growth. This is driven by a number of significant factors, including a common understanding of required grid flexibility, a desire to reduce the effects of greenhouse gases on the environment, stronger policies for valuation of ancillary services, creative energy storage policies that include financial incentives to provide long-term revenue stream certainty, and a desire to reduce reliance on limited access to hydrocarbon resources. It is important to note that for many areas outside of North America, the access to inexpensive, reliable sources of natural gas is a significant concern, thereby enhancing the development of policies promoting energy storage development.

It is also worth noting that the existing pumped storage projects in the U.S. were developed in the absence of detailed system operations models and ancillary service revenue structures. System planners understood the grid to be a careful balancing act requiring an integrated approach to demand forecasting and associated generation, transmission, and energy storage. Today, pumped storage systems are pumped

[8] The term "single speed" is used to describe conventional pumped storage units with synchronous speed machines. Additional detail on single and adjustable speed units are presented in Appendix B.

storage systems to provide electric grid support through ancillary services such as network frequency control, grid stabilization, reserve generation, and integration of variable renewables is significantly broadening the value of pumped storage technology.

There are several reasons why Europe and other parts of the world are developing new pumped storage projects; some are directly applicable to the U.S., and some are not. Primary drivers include:

- Some areas of Europe have stronger, well-defined ancillary service markets.
- High volatility between on-peak/off-peak electricity prices drives energy arbitrage opportunities.
- Pumped storage is often considered the only proven grid-scale energy storage technology.
- Europe lacks the natural gas reserves that are available in the U.S., and therefore must incorporate long-term system integration planning.
- The strong push for "carbon free generation" leads to advances in solar, wind and other renewables, which causes the need for energy storage products.
- There are various incentives for energy storage, including capacity payments and reduce transmission interconnection fees.
- Regulated utilities build and operate pumped storage plants as a key load management element of their operations.

1.4 4.0 NHA RECOMMENDATIONS TO ADDRESS PUMPED STORAGE DEVELOPMENT CHALLENGES

NHA has developed policy recommendations to stimulate new pumped storage development. Providing better recognition of pumped storage benefits and services will provide the needed market signals for these projects. In addition, several existing regulatory challenges should be addressed to streamline the long approval times. In general, new hydropower projects take twice as long to permit as other energy sources including solar, wind, or natural gas projects. Improving the current licensing process for low-impact pumped storage projects (closed-loop or off-channel systems) similar to how FERC has recently addressed other hydropower development opportunities would reduce this disparity[9].

[9] This includes recently enacted MOUs with state and Federal agencies to streamline the FERC licensing process.

Policy Recommendations

1) Create market products that allow flexible resources to provide services that help meet electric grid requirements, including very fast responding systems that provide critical capacity during key energy needs.[10]

Energy storage systems have multi-functional characteristics, which complicate rules for ownership and operation among various stakeholders. Regulatory agencies have not defined ownership structures and flexible business models in which storage can be used for both generation and grid support purposes. Policy rules regarding allocation of costs incurred by adding energy storage systems to the grid need to be more clearly developed.

Energy storage applications could enable bi-directional energy flows, creating potential revenue recognition challenges for current tariff, billing, and metering approaches. The results of future policy discussions should help inform the development of new market structures and rules to accommodate and capture the benefits of pumped storage and other energy storage technologies.

Policies should take into account the ability of a storage technology to support the electric grid, including speed of response. Recent studies in California recommend definitions as 5 MW/sec (fast) and 15 MW/sec (ultrafast) at the plant level (i.e. FERC Order 755). Many of the existing ISOs/Regional Transmission Organizations (RTOs) such as CAISO, PJM, and others have products and markets that allow resources, such as energy storage, to earn revenues by providing services to the system. To the extent that non-RTO regions do not allow resources to participate and provide system benefits, we encourage these regions to create products that they can procure from flexible resources and provide payment for those services. In addition, NHA recommends further evaluation of treating bulk energy storage as a separate and distinct electricity infrastrucure asset class (i.e., Balancing Asset or Compensating Asset), capable of relieving grid stresses through the absorption of excess energy during low demand periods or rapidly providing capacity during periods of peak demand.

2) Level the policy playing field for pumped storage hydropower with other storage technologies.

While pumped storage hydropower can meet many of the grid-scale energy storage needs, no single storage system can meet all grid demands. A wide variety of storage technology options is being proposed and evaluated for utility-scale storage and end-user energy management applications. Still, greater than 98% of the worldwide energy storage is in the form of pumped storage hydropower. As a proven technology, pumped storage has been shown to be cost effective, highly efficient, and operationally

[10] One example of this important step includes FERC's Order 755 (*Frequency Regulation Compensation in the Organized Wholesale Power Markets*), which supports the use of energy storage facilities for ancillary services (October 20, 2011).

flexible. The FERC and other regulatory agencies have treated pumped storage primarily as a generating resource and have not included it in many significant energy storage discussions.

NHA recommends that any new market rules, incentives for development, as well as other policies should recognize and treat pumped storage the same as other forms of energy storage.

3) ***Recognize regional differences in the nation's generation portfolio and the different roles storage technologies play in different regions.***

Pumped storage and energy storage in general can play very different roles in different regions of the U.S. In regions with high percentages of variable generating (non-firm) renewables such as wind and solar, pumped storage hydropower can function as a renewable integration tool. This is the current European model behind the construction of new pumped storage hydropower plants, projected to total more than 27 gigawatts of capacity by 2020 in Europe (Ecoprog, 2011). In regions with large coal-fired or nuclear steam plants, pumped storage plays a levelizing role and peaking role. This is the case of the existing pumped storage hydropower fleet in the eastern U.S., as well as countries such as Japan and France.

4) ***Recognize the energy security role pumped storage hydropower plays in the domestic electric grid.***

In the U.S., pumped storage has been typically built on the 1,000 MW scale but in actuality can be built to virtually any scale. The generating capacity of existing plants worldwide range from less than 1 MW to approximately 2,700 MW (e.g., Bath County Pumped Storage Project, Virginia). Larger capacity plants are currently under consideration globally. As the primary grid-scale storage technology in the world, pumped storage plays a critical energy security role, but there is currently no recognized revenue stream for providing this key service. Existing pumped storage plants in every region become a key "energy security" plant within a given control or balancing area. In the event of a major disturbance such as a major steam unit trip or a transmission line failure, pumped storage black start capability or spinning reserve can be called upon to restart or stabilize the grid on very short notice. Full generation from the project can be accomplished to cover the energy deficit for longer periods, depending on reservoir level and size. Pumped storage can also respond to decremental needs such as a significant wind ramping event during low consumer demand periods, maintaining grid stability by rapidly responding to generation oversupply in the pumping mode. In addition, pumped storage facilities are resilient to unexpected changes in weather patterns, including drought or low water years, because the water used for generation is recycled from upper to lower reservoir, and not released to the natural stream flow (U.S. DOE/Homeland Security, 2011). These are critical energy security functions that often go unrecognized, underappreciated, and most notably, undercompensated.

5) ***Establish an alternative, streamlined licensing process for low-impact pumped storage hydropower such as off-channel or closed-loop projects.***

In general, new hydropower projects take twice as long to permit as other energy sources including solar, wind, or natural gas projects. NHA suggests that FERC consider changes to the current licensing process for low-impact pumped storage projects similar to how they have recently streamlined other hydropower development projects. In particular, there are certain categories of pumped storage projects that would have a minimal effect on the environment such as off-channel projects or closed-loop projects. In these instances, environmental review and conditions should be limited to the project's proposed changes to current conditions, and the FERC approval process could mimic the FERC exemption program to streamline project permitting. Broadening the scope of projects that could move through a streamlined process would help lower approval costs and provide greater licensing certainty without compromising environmental protections. Under the FERC's comprehensive development standard stemming from 10(a) of the Federal Power Act (FPA), the FERC can approve a hydroelectric project provided it is "best adapted to a comprehensive plan for improving or developing a waterway." If the water source used for filling and providing make-up water for a closed-loop pumped storage project comes from a non-riverine water source such as groundwater or recycled wastewater, there would be no waterway affected by the project. In these cases, the FERC should consider these projects in a new, minimal-impact category to reduce the length and complexity of the licensing process. The FERC could advance the licensing process through a shorter process but have "off-ramps" if unanticipated issues arise. NHA is encouraged to hear that FERC is currently considering a two-year licensing process for these types of projects and new regulations could codify this process. Other relatively low-impact proposed pumped storage projects, such as those utilizing two existing reservoirs, may also be appropriate candidates for future consideration of a shortened licensing process.

6) ***Improve integration of Federal and state agencies into the early-stage licensing processes for pumped storage hydropower.***

NHA and the overall hydropower industry continue to work closely with FERC to streamline the licensing process for those projects with obvious minimal environmental constraints; however, additional efficiency can be realized through process improvements related to coordination with other Federal and state agencies. By implementing the Integrated Licensing Process, FERC has helped licensees coordinate with many agencies; however, in some areas of the country, there continue to be overlapping regulatory processes that cause significant delays in the licensing process. These challenges should be streamlined for development of environmentally favorable pumped storage sites, and resource agencies should be encouraged to participate early in development reviews. This would minimize additional information requests, resolve disagreements early in the process, and allow for speedy processing of permit applications later in the process for those projects that clearly have minimal environmental impacts. All resource agencies performing their own environmental reviews should be encouraged to work concurrently with the FERC process to coordinate and not duplicate the environmental review process.

7) ***Facilitate an energy market structure where transmission providers benefit from long-term agreements with energy storage facility developers.***

NHA requests that FERC develop policies that allow RTOs and ISOs to enter into long-term fixed-price contracts with energy storage project owners, including pumped storage facilities. One such policy would be to lift or modify the *Avista Restriction* for grid-scale energy storage projects providing storage-only services. These policies could include fixed-price contracts that provide the procurer long-term ancillary services for the term of the contract and the benefit of energy storage services uniquely suited to manage the growing penetration of variable energy generation.

For such facilities to be financed, transmission providers need authorization to enter long-term agreements with energy storage facility developers. Pumped storage facilities built decades ago were primarily built as rate-base cases by regulated utilities; however, in most areas of the country except the southeastern U.S., this model no longer applies. Today, much of the nation's energy infrastructure is now being developed by independent power producers who lack utility rate base cost-recovery structures. Transmission organizations and ISOs are most able to realize the full value of grid-scale energy storage facilities. Unfortunately, FERC precedent poses a major barrier to long-term contracting with such users of storage services (ECE, 2011). [11]

[11] In their 2011 paper, ECE detailed FERC's previous challenges with encouraging transmission organizations and ISOs to use new and more efficient technologies while dealing with pumped storage projects, and maintaining the separation of generation and transmission markets [*Nevada Hydro Co., 122 FERC ¶ 61,272 (2008)*, and *Western Grid Development, LLC, 130 FERC ¶ 61,056 (2010)*]

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1.6 Appendix A – Historical Development and Future of Pumped Storage

A.1 Historical Pumped Storage Development, Historical Operational Characteristics and Function

Since the first pumped storage project came on-line in Europe in the early 1900s and in the U.S. around 1930, pumped storage hydropower has provided significant benefits to the energy transmission and power supply system including energy storage, load balancing, frequency control, and reserve peak power generation. [12]

Historically, a pumped storage project's primary function has been to balance load on a system and allow large, thermal generating sources to optimize generation by running near peak production. As described in the main body of this paper, this process allowed pumped storage to take advantage of excess off-peak energy from these large (thermal or nuclear) generators and store the energy for release during peak demand. Accordingly, the primary development of pumped storage power occurred in the 1960s, 1970s, and early 1980s in parallel with the construction of a large number of nuclear power stations. The worldwide evolution of the total installed nuclear power and the total installed pumped storage power over the last 45 years is depicted in Figure A-1.

[12] The earliest known use of pumped storage technology was in Switzerland in 1882. For nearly a decade, a pump and turbine operated with a small reservoir as a hydro-mechanical storage system. Beginning in the early 1900s, several small pumped storage plants were constructed in Europe, mostly in Germany. The first unit in North America was the Rocky River Pumped Storage plant, constructed in 1929 on the Housatonic River in Connecticut.

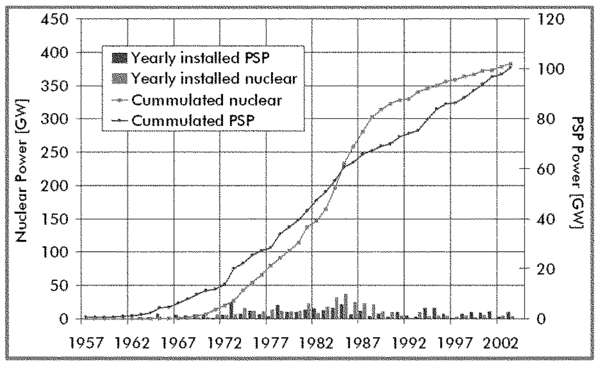

Figure A-1: **Worldwide Installed Nuclear and Pumped Storage Project Development History (Source: Alstom Power and UDI database).**

The next major breakthrough, the adjustable-speed design, was developed mainly in Japan. Whereas, with single speed units, the only known variable available to the operator for most of the early designs was water flow, which was controlled by moving the wicker gates. However an adjustable-speed motor-generator allows the shaft rotation rate to change as well. By optimizing the two variables, the unit can be dispatched at optimum efficiency over a large power range. The first adjustable speed system, Yagasawa Unit 2, was constructed for the Tokyo Electric Power Company (TEPCO) and became operational in 1990.

It is worth noting that existing U.S. pumped storage projects were developed in the absence of detailed system operations models and ancillary service revenue structures. System planners understood the grid to be a careful balancing act requiring an integrated approach to demand forecasting and associated generation, transmission and storage. Today, pumped storage systems are becoming recognized as much more than simply load shifting energy storage projects. The ability of pumped storage systems to provide electric grid support through ancillary services such as network frequency control, grid stabilization, reserve generation, ***and*** integration of variable renewables is significantly broadening the value of pumped storage technology.

A.2 Summary of Operating Pumped Storage Facilities Worldwide

While other energy storage technologies have been developed and many are being investigated, pumped storage hydropower is by far the most widely used energy storage application, with more than 127,000 MW installed worldwide (EPRI, 2010). This worldwide total is expected to exceed 203,000 MW by 2014, representing an annual growth rate of 10% (Ingram, 2010). The current geographic distribution of the worldwide pumped storage fleet is depicted in Figure A-2.

In comparison, there are currently 40 pumped storage projects operating in the U.S. providing more than 20,000 MW, or nearly 2%, of the capacity for our nation's energy supply system as shown in Figure A-3 (HDR, 2011). The most recent project constructed in the U.S. was completed in 2011, a 40 MW pumped storage facility developed in southern California as part of a larger water supply project. The majority of the other 39 projects were constructed more than 30 years ago, in coordination with large thermal or nuclear facilities.

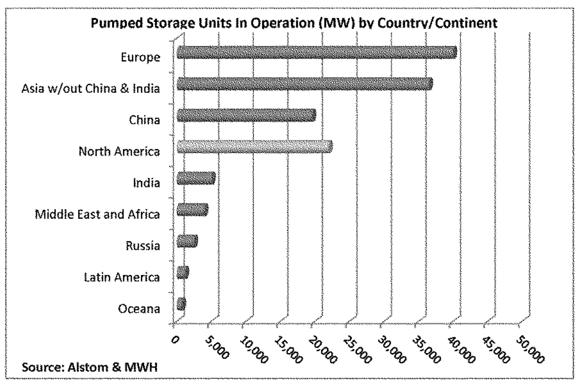

Figure A-2: **International Distribution of Pumped Storage by Country/Continent.**[13]

[13] Japanese pumped storage project is included above in Figure A-2, in the "Asia without China and India" category, it is estimated that Japan has approximately 26 GW of installed pumped storage capacity.

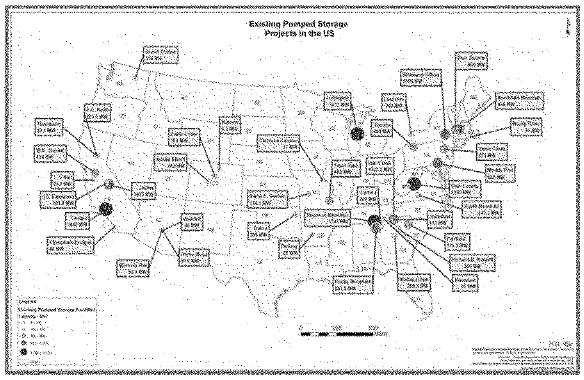

Figure A-3: **Existing Pumped Storage Projects in the U.S. (HDR, 2011).**

A.3 Current Planned Pumped Storage in the U.S.

In the last few years, there has been a significant increase in the number of preliminary permit applications filed with FERC for pumped storage projects. While a preliminary permit does not authorize construction, it is a strong indication of the interest in new pumped storage development. As of January 2012, FERC has granted preliminary permit applications for more than 34,000 MW of new pumped storage projects in 22 states, with greater than 66% of current permits are for closed-loop sites. Figure A-4 presents pumped storage projects currently under development in the U.S. and Figure A-5 shows the increase in recent pumped storage project permit applications with FERC (highlighting closed-loop-type projects).

While there is significant interest in developing pumped storage projects, there remain significant challenges facing the completion of new projects, ranging from licensing, environmental misconceptions, the regulatory treatment of pumped storage versus traditional hydropower projects, and a lack of long-term markets needed for large capital investments. The main body of this paper discussing these challenges in detail, and provides recommendations for addressing each issue. In addition, NHA has been working with FERC and the U.S. Department of Energy on resolving many of the challenges facing pumped storage development in the hope of facilitating the growth of this key domestic energy security resource.

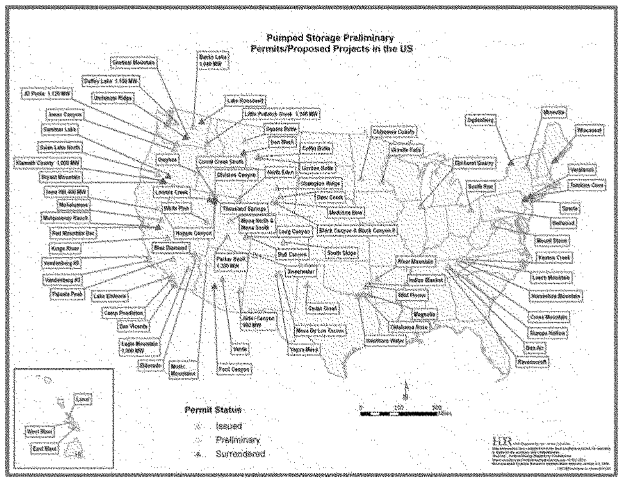

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Figure A-4. **Pumped Storage Projects under Development in the U.S. (HDR, 2011).**

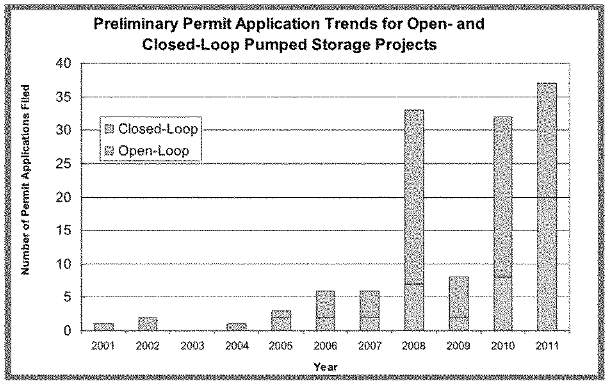

Figure A-5: Preliminary Permit Application Trends for Pumped Storage Projects (FERC, 2012).

1.8 Appendix B – Adjustable-Speed Pumped Storage and the Value to the Overall Electric Grid

Globally, there are approximately 270 pumped storage plants either operating or under construction, representing a combined generating capacity of over 127,000 MW. While the majority of the plants use single-speed pump-turbine machines[14], 36 utilize adjustable-speed machines - 17 of these are currently in operation (totaling 3,569 MW) and 19 are under construction (totaling 4,558 MW). All of these units are located in Europe, China, India, or Japan[15]. As stated in the main body of this paper, adjustable-speed generation units are able to modulate input pumping power and provide significant quantities of frequency regulation. A new key ancillary service opportunity that may be realized through adjustable-speed technology is the added need for regulation at night to accommodate variable renewable energy inputs. The ability to provide regulation service in both pumping and generating modes also has a benefit in the form of reduced carbon fuel consumption and climate change (reduced warming). In this regard pumped storage is an in-kind compliment to renewable energy technologies. The more energy supplied by renewable energy sources that are used to pump means less carbon based fuel energy is used for pumping. Therefore, when the pumped storage unit is providing regulation service in generation mode it is more likely to be using energy that has come from renewables. On the other hand, if combustion turbines or coal units are used for regulation, then as more renewable energy sources are connected to the grid there is a greater use of natural gas and coal for regulation – which somewhat counter acts the benefits of increased energy from renewables. A representation of the benefits of adjustable-speed technology is presented graphically in Figure B-1.

B.1 Features of Adjustable-Speed Pumped Storage

The traditional pump-turbine equipment design in the U.S. is the reversible single-stage Francis pump-turbine, which acts as a pump in one direction and as a turbine in the other. Although this technology is proven and has worked well for over six decades, there are limitations to its performance, particularly when it comes to the pump mode. While design enhancements over the years have improved unit efficiency and power output, frequency regulation while in the pump mode is not possible with single-speed equipment because traditional synchronous machines are directly connected to the grid and operate at a constant speed and constant input pumping power. In the turbine mode, the energy produced by each unit can vary, but does not operate at peak efficiency during part load. Adjustable-speed machines enable

[14] The term "single speed" is used to describe conventional pumped storage units with synchronous speed machines.

[15] In Japan the use of the term "variable speed" is common, where in Europe and other parts of the world, the term "adjustable speed" is often used. It is noted that early technical papers in Japan do use the term "adjustable speed". [Example: Kita, E., Mitsuhashi, K., Juwabara, T.' and Shibuya A.,; "Design of Dynamic Response of 400 MW Adjustable Speed Pumped Storage Unit and Field Test Results for Ohkawachi Power Station", presented July 27, 1995; IEEE-PES Summer Meeting, San Francisco, CA.]

the power consumed in the pumping mode to be varied over a range of outputs. Modifying the speed also allows the turbine to operate at peak efficiency over a larger portion of its operating band. Because adjustable-speed technology is well suited to integration of variable renewable generation, many of the proposed new pumped storage projects are considering adjustable-speed machines.

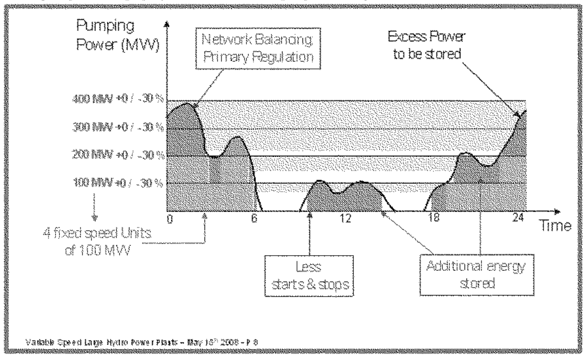

Figure B-1: **System Reserve and Power Storage from Adjustable-Speed Pumped Storage (Source: Alstom Power).**

Adjustable-speed pump-turbines have been used since the early to mid-1990s in Japan and the late 1990s in Europe. A main reason that adjustable speed pumped storage was developed in Japan in the early 1990's was the realization that significant quantities of oil burned in combustion turbines could be reduced by shifting the responsibility for regulation to pumped storage plants. In a conventional, single-speed pump-turbine, the magnetic field of the stator and the magnetic field of the rotor always rotate with the same speed and the two are coupled. In an adjustable-speed machine, those magnetic fields are decoupled. Either the stator field is decoupled from the grid using a frequency converter between the grid and the stator winding, or the rotor field is decoupled from the rotor body by a multi-phase rotor winding fed from a frequency converter connected to the rotor.

A cycloconverter was an early adjustable-speed technology implemented and provides the rotating magnetic field in the rotor (see Figure B-2). There are some limitations with this type of adjustable-speed machine. Cycloconverters cannot be used to start the unit in the pumping mode, which means that an additional static frequency converter is required in the powerhouse to start the unit. Cycloconverters also absorb reactive power, which needs to be compensated by converters or provided by the generator. Recently there have been improvements in large voltage source inverters that enable the stator magnetic field to be decoupled from the grid. This type of conversion is often more popular than the cycloconverter, as this method does not absorb reactive power and the inverters can be used to start the project in the pumping mode.

A double-fed induction motor (DFIM)-generator is the current standard design for adjustable-speed machines. Generally, generator-motors are larger in size and have smaller air gaps than conventional machines. The stator is similar to that of a conventional generator-motor. The rotor requires additional features including at least one slip ring per phase (for three phases) and additional protection from mechanical stresses. This protection is in reinforcement of the rotor winding overhang and rotor rim. The rotor rim of an adjustable-speed machine carries an alternating magnetic field which may require additional design considerations. As the voltage and current ratings of gate-controlled switches (GTOs, GCTs, IGCTs and IGBTs) have increased, back-to-back voltage source converters have become relevant for feeding rotor windings of the DFIM.[16]

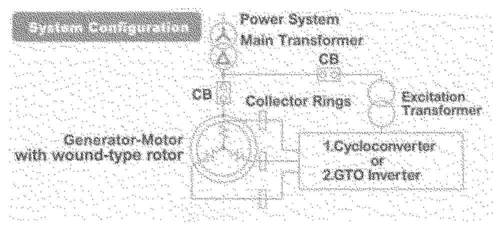

Figure B-2: **Schematic of a Cycloconverter or Inverter-Style Adjustable-Speed Motor-Generator (Source: Toshiba).**

B.2 Summary of Adjustable-Speed Benefits

Adjustable-speed pumping enables tuning of the grid frequency at night or during system disturbances or anomalies, as well as the use of fluctuating renewable wind or solar energies to pump water to the upper reservoir. The principal feature of the adjustable-speed units is that the input power is adjustable when carrying out automatic frequency control (AFC) while filling the upper reservoirs. This flexibility is frequently employed by adjusting the speed of units during light load periods such as the middle of the night and during holidays. In addition, pump operation with adjustable-speed units is extended in comparison to single-speed units, enabling more real-time response to grid conditions.

[16] Various sources; including personal communication (Peter Donalek, MWH) and Suul, J. A.; "Variable Speed Pumped Storage Hydropower For Integration of Wind Power in Isolated Power Systems", Norwegian University of Science and Technology, Norway, June 2008.

As discussed above, globally, there are 270 pumped storage stations either operating or under construction, with 36 units consisting of adjustable-speed machines (8,127 MW). While several projects in the U.S. in licensing, initial design or planning phase are evaluating the use of adjustable-speed technology, all of the existing projects (including those under construction) are located in Europe, China, India, or Japan. To gain acceptance of this technology in the U.S., the added cost of adjustable-speed technology must be offset by valuation in the ancillary services market, which is one of the key market points of this paper.

Table B-1 presents a summary of the various features and benefits of adjustable-speed pumped storage technology, including technological and economical advantages.[17]

Table B-1: **Features and Benefits of Adjustable-Speed Pumped Storage Technology.**

Feature	*Technological Advantages*	*Economic Advantages*
Adjustable pumping power	Frequency regulation in pumping mode by accommodating variable supply	Additional ability to quickly ramp up and down to support more variable renewable energy resources
	More efficient use of equipment, reducing the need for thermal plant cycling; critical for avoiding greenhouse gas emissions	Operations and maintenance cost reduction and increase of equipment lifespan; greenhouse gas offsets if market develops
	Able to take advantage of shifts in grid dynamics to effectively manage variable energy supply and capture and store lower cost energy	Cost minimization and operation of existing units at peak efficiency; support growth of additional renewable energy resources
	There is an increase in energy generation due to the fact that the turbine can be operated at its peak efficiency point a under all head conditions.	This results in an estimated increase in energy generated on the order of 3% annually.
Faster power adjustment and reaction time	Improved balancing of variable energy units (wind/solar) and coordination of overall energy mix	More stable equipment translates into risk reduction and increased reliability of the domestic electric grid

[17] Note: While there are significant advantages with adjustable-speed pump-turbines, the majority of pumped storage projects under development around the world continue to be single-speed pump-turbines. A primary reason for this is that there remains substantial grid flexibility in many regions of the world where there are strong transmission interconnections and unconstrained hydropower operations, two conditions that typically do not exist in the U.S.

The CHAIRMAN. Thank you, Mr. Seifarth. I think you recognize you are looking at two women that believe a lot in our hydro resources and the opportunities for storage through our hydro. Thank you all for your comments this morning and the discussion that we are about to have.

We talk a lot in this Committee about the breakthrough that we saw with natural gas when hydraulic fracturing came along. We were at a point where everyone was talking about, you know, "the end is near" type of a thing and, quite honestly, our technologies are always moving forward. We certainly hope that they are. And that was clearly a breakthrough when it comes to the oil and gas sector and how it has advanced forward.

We have heard about the opportunities that we have now with energy storage technologies, but you also, all of you, I think, have raised a few of the challenges that we have. You have some scientific limitations. I think it was you, Dr. Sprenkle, who said we are going to need a new manufacturing paradigm. Industrial acceptance is an issue.

I guess the question that I would pose to all of you is, in order to really advance our energy storage technologies, do we need a breakthrough? Do we need, kind of, the hydraulic fracturing equivalent in order to advance us to that next level? And if so, what is it? Or do you think that we are just going to continue to move along as we have been? Again, I throw it out to each of you for your input here.

Go ahead, Dr. Sprenkle, you get to start.

Dr. SPRENKLE. Thank you.

So, there are tremendous opportunities for breakthroughs in this field. What we're seeing now is where there's high value, we can make it work, but if we want energy storage, kind of, ubiquitously deployed across the grid, it's going to have to be much cheaper. It's going to have to last a lot longer than it does today, and we're going to have to show that safety. And that's what, through the R&D efforts is, hopefully we can drive that down to where it's a natural grid asset to put on there. And for most of the, kind of, lower value applications, storage can be able to provide that service, in my mind.

The CHAIRMAN. Mr. Kathpal?

Mr. KATHPAL. From our perspective in a business, the good news is we don't need a breakthrough, but breakthroughs are going to happen, as Dr. Sprenkle suggests.

So the technology we have today of lithium-ion is mature and is at a cost that is appropriate for a lot of grid and utility applications and its cost will continue to decline.

Today we see it as already available to be in a mainstream utility planning and procurement type of setting. And the good news is that we will continue to have further technology evolution that will only open up more applications and lower costs to consumers further.

The CHAIRMAN. Good.

Mr. Moores?

Mr. MOORES. Yeah, I agree with that.

For me it was always a matter of economics really. Can you get cheap enough batteries, abundant production of batteries that can be used in numerous applications, ultimately electric vehicles is really what's kicked this off.

And lithium-ion cells, you've had that really the last two and a half to three years. Now we see lithium-ion cell costs as one big contract under $140 per kilowatt-hour. Even in 2009 this was $1,000 per kilowatt-hour, in and around.

So it was a case of actually waiting for these industries to mature and to become cheap and to get up to scale and other R&D benefits through the cathode and anode. But ultimately, it's coming down to scale.

The battery is getting better as well, not just through the actual cell itself, but you build these lithium-ion batteries into packs and then they go into vehicles or they go into energy storage units. Now there's technology software management systems that control the energy within those battery packs, so that's improving battery life without necessarily the batteries themselves improving. The whole system is becoming far more intelligent, and I think that's going to drive this next five years.

The CHAIRMAN. Very good.

Mr. Seifarth?

Mr. SEIFARTH. I agree with Simon.

The technology there is in the electronics. And it's interesting because we're still talking about hydro after 150 years. It's the old reliable and it's changing with the times as well.

The innovation in hydro is coming with today's high technology pumped storage facilities having the ability to react in milliseconds through a combination of hydraulic innovations and also electronic innovations, you know, there's automation, automation controls, frequency control, full converter frequency control for hydroelectric turbines.

We have a reliable energy source in hydro and what we need now is some legislation to help advance that with the newer technologies. Think of it in a way of having that great, old Chevy car you had and the engine is still solid as a rock and you're getting more efficiency out of that car by putting in more technology. So it's the right sustainable thing to do.

And after all these years, we're still, you know, lucky enough to be talking about hydro as we talk about grid reliability, black start capability and the security of the country.

The CHAIRMAN. Very good.

Thank you, all.

Senator Cantwell.

Senator CANTWELL. Thank you, Madam Chair.

Well, it is hard not to follow up on that. Mr. Seifarth, what kind of resiliency do you think this investment also makes against the changes to snowpack and the fact that continuing to make investments in storage is also important from that perspective of the change in dynamics we are seeing?

Mr. SEIFARTH. Well, I think there you're seeing a lot of scientists and others looking at some closed loop systems. And those, what I mean by closed looped, obviously, we have a captive upper and lower reservoir that's not necessarily connected to an existing water stream or water source.

In addition to that, you see owners retrofitting their new plants based on the changes that they're seeing in the hydrology of the plant. There are owners right now who are actually putting minimum flow units into their units so that they can aerate and provide power even with changing environmental conditions. So hydro is extremely adaptable and again, it's keeping up with the technology as it presents itself in a changing climate.

Senator CANTWELL. Dr. Sprenkle, if PNNL and other labs stopped doing the research, would somebody pick up the slack?

Dr. SPRENKLE. For the new technologies that are coming out? No. As you've seen with lithium-ion. So, the first paper on lithium-ion was issued in 1976. The first materials that are used today were in the late '70s. It took until '91 to get that material into the first commercial product and until today to get to the prices where it's competitive. And so, there is a long development time with these, to get these to a level of maturity where they can make that transition out.

That's—we saw it with lithium-ion. That's often beyond the time scale of a lot of companies.

Senator CANTWELL. And so, what would you say the priorities are to keep focused on, from a lab perspective?

Dr. SPRENKLE. I think, as we kind of outlined in my opening statement, it is materials. We need to focus on earth-abundant materials that inherently have a low cost. We need platforms that can take that and quickly get it to a point where a company can come in and there's some level of confidence with that, that it will work, that it will be reliable and it can be deployed out there.

From a utility perspective, they want to see something that is robust and reliable and we have to be able to take those quickly to that point.

Senator CANTWELL. What do you think about the fact that we have Mr. Kathpal, to Mr. Seifarth—I mean, it's a broad spectrum of storage. What does that tell you?

Dr. SPRENKLE. Well, I think we have, you know, there's a place for everything in this. I mean, we need that storage capacity, however you can get it, whether it's bulk storage or whether it's distributed at the home to community, to substation, to central generation and trying to firm up baseload. You know, there's a role for it in all aspects. And those may all not be the same technologies. There may be different performance profiles that favor one over the other for those applications.

Senator CANTWELL. Well, I guess that was my point, that the breadth and depth of the research that you're doing can apply in lots of different things.

The one thing that I did learn in the private sector that I thought was probably the most valuable thing is that you can have the advent of technology.

Dr. SPRENKLE. Yeah.

Senator CANTWELL. But it can take sometimes as much as 20 or 25 years for the business model to develop.

Dr. SPRENKLE. Yeah.

Senator CANTWELL. So it's a long time.

[Laughter.]

But it's well worth the pursuit. I just hope that we continue to make this investment. And I think for us in the Pacific Northwest who want to keep marrying up the efficiencies of smarter intelligence that software delivers to renewables, but also into storage and taking advantage of those resources, we want to keep making the investment. To me, even if it was just on the hydro side, it would be well worth the investment. But obviously, with everything from electric cars to everything else, there's lots of opportunity. So I hope we make the right decisions here.

Thank you, Madam Chair.

The CHAIRMAN. Thank you, Senator Cantwell.

Senator Gardner.

Senator GARDNER. Thank you, Madam Chair.

Thank you to the witnesses for being here today.

We talked a little bit about the electronics and some of the systems that are helping make battery storage more efficient, more productive. Could you talk about some of the technology, the physical technology, of batteries, like 3D lithium-ion structures?

Is that where we're heading, sort of, the 3D battery, the structure with, like, the foam batteries?

Dr. SPRENKLE. I think there are a lot of opportunities in that, that agile manufacturing, wherever you can get these out, with these different systems.

It is still, I think, in the future yard looking at for grid-scale batteries, ultimately, something that has low cost, you know, sodium, iron, those types of systems and that can be done in an aqueous base so you'd have that inherent safety.

Senator GARDNER. Dr. Sprenkle, in terms of the safety issue itself—one of the interesting articles that came out during the hurricanes over the past month, I believe it was Florida where Tesla had reprogrammed certain Tesla vehicles to allow the battery to have a further range because it was just a software that they could have purchased additional range for the Tesla if they paid additional dollars, but Tesla gave everybody a two- or three-day window or a week, whatever it was, to have the extended range just through a software update.

So when we are doing battery storage, battery development research, are we also looking at the cyber components of what it means to just do a software update that could affect somebody's battery?

Dr. SPRENKLE. Yeah.

Senator GARDNER. How does that work?

Dr. SPRENKLE. There is a strong cyber component to storage, just in—it can offset a lot of things, but you also have to be able to control that because it can take or give energy, especially to the grid in there.

So, yeah, those are the things that I think, probably just now, that people are really starting to focus on as we do get more deployments on it from the R&D side of it. You have focus more on the materials and technologies at this point, so——

Senator GARDNER. Dr. Sprenkle, as we get further into the recovery of and the rebuild of infrastructure in Puerto Rico, what opportunities should we be looking at with the Department of Energy to look at battery storage as part of the solution as we rebuild Puerto Rico's grid?

Dr. SPRENKLE. I think you look at it from a resiliency perspective. You look at that hierarchy of resiliency.

We've already seen reports coming out of Florida where homes that had solar plus storage and, you know, critical emergency shelters that had solar plus storage were able to provide those essential services. If you have that at the home and then you have storage integrated at the community and then you have it at the substation. You have, no matter where you're impacted, you've got those different levels.

There is the analysis in trying to figure out where the value proposition is. Ideally, we want that distributed throughout. And to do that it's going to have to be cost-effective for all those applications in order to get that shared amount of storage out.

So those are areas where DOE can, both in terms of the analysis, looking at it and the development and how those systems integrate and can aggregate when needed.

Senator GARDNER. We have talked a little bit about hydropower. We have, obviously, several different opportunities with the pump back operations in Colorado, production facilities and the need to store additional water and also the need to build out existing structures that lack a hydro component.

Permit reform has to be part of our solution here as well when we look at permitting new water storage facilities, permitting new hydropower production facilities. I think that has to be something that the Committee looks into because you could have an opportunity for hydropower, but no permit means you cannot move forward on it. I think that is something that this Committee has to address.

And finally, I would just say that over the past weekend, we had some great stored energy occur in Colorado in the form of a lot of white powder—and it is going on our ski resorts that are now opening in mid-October. I appreciate that opportunity for that storage of water to brag a little bit about Colorado.

The CHAIRMAN. Send some of it our way, please.

[Laughter.]

Senator Franken.

Senator FRANKEN. Thank you, Madam Chair, and Senator Gardner, thank you for bringing up Puerto Rico and the storage there because after the last couple months, or few weeks, we have seen Hurricanes Harvey, Irma, and Maria really demonstrate the risks that the grid faces from extreme weather.

Some communities in Texas and Florida underwent days or weeks without power, and now American citizens in Puerto Rico and the Virgin Islands are facing a humanitarian crisis and the Federal Government needs everything it can get to help. It could take many months, not weeks, to get power back to these communities. This is, obviously, a serious risk to people's health and safety. It affects hospitals, water treatment and pumping systems, et cetera. And our economic supply chain is disrupted as well.

We met with FDA Commissioner Gottlieb last night, the HELP Committee, at an informal gathering with him and he is very concerned about the pharmaceutical plants in Puerto Rico. I think they produce 25 percent of our exports of drugs. There are drugs there, 13 of which are not produced anywhere else, and the FDA says we are really short. This is really an emergency.

We know we are going to see more hurricanes and extreme weather events. With 80 percent of the grid in Puerto Rico destroyed, we need to rebuild and we need to rebuild a more resilient grid that is able to withstand the effects of these disasters.

Mr. Kathpal, your company, AES, provides power to Puerto Rico and to the Virgin Islands. How can we rebuild the grid in a more resilient way? And what role do you see for energy storage?

Mr. KATHPAL. Sure. Thank you for the question, Senator Franken.

We have no doubt that storage will play a role in the rebuilding and in the new form of grid in Puerto Rico and potentially other affected places.

We're seeing some response organizers right now proposing pop-up solar and storage to power hospitals and other critical facilities. That's one way that storage can bring near-term resilience in the wake of a disaster and we also believe that there's going to be a role for storage at all levels of the grid, from the large-scale down to the distribution systems and then behind the meter as well as in microgrid applications.

Senator FRANKEN. You know, as Congress considers a supplemental aid package to help the people of Puerto Rico and the U.S. Virgin Islands, I really think it is critical that a package allows infrastructure to be rebuilt in a renewable and sustainable way.

I think this is a tragedy, obviously, but given that we have to rebuild this from approximately 80 percent destroyed, I think that it is an opportunity too, to build in a way that is resilient and which also helps reduce the threat of damage in future disasters.

And I just want to ask my colleagues to—I have discussed it with the Chairwoman. I think this is something that we could all get behind on both sides of the aisle which is just to take this disaster and use it to give these two territories the kind of resilient infrastructure that they will need to survive the next one so we don't have to go through this kind of dire emergency where people's lives are at stake and where it is impossible because, I believe, Puerto Rico is an island and I think the Virgin Islands are islands, too, surrounded by ocean.

[Laughter.]

I really think that this is something that we should do in a bipartisan way, in a way that is just smart and also where we could learn something and also we could gain something.

So, that is just a little speech I have made to use the rest of my time.

The CHAIRMAN. Thank you, Senator Franken. Know there are many members of this Committee that are very interested in how we can help Puerto Rico and the Virgin Islands build an energy grid that is more sustainable, that is more resilient, and making sure that we do this in a way that provides benefit.

There is one thing about just being able to turn the lights on today. There is another thing about ensuring that there is a better path forward. I noted that you, Dr. Sprenkle, used the term, "regional technology demonstrations." It just seems that through the tragedy we are seeing on the islands, there may be an opportunity here as we look to these islanded grids and figure out a better way. So——

Senator FRANKEN. Including more microgrids, in other words, where——

The CHAIRMAN. You know I love microgrids.

Senator FRANKEN. You and I both.

The CHAIRMAN. Yes.

Senator FRANKEN. I think so many of us love, love microgrids.

The CHAIRMAN. Senator Risch, do you love microgrids?

Senator RISCH. Well, I am going to talk about something else.

The CHAIRMAN. Alright.

[Laughter.]

Senator RISCH. First of all, let me say, thank you for holding this hearing, Madam Chairman.

In Idaho, at the Idaho National Laboratory, we have been doing this for a long time. In fact, every time there is a launch from Florida that goes into space it carries products that were manufactured at the lab for storage and for generation for years and years as they make a space voyage. So we are into that.

But I am going to talk about something more down to earth, if you would. They are starting to discuss a very significant proposal in Idaho for, I guess, what people refer to as "repumping project" where, when electricity is not used during the day, it is used to pump water back up and use it again at night. There is some of this, I know, that has gone on. Are any of you familiar with that technology, that storage technology? Have any of you worked any projects like that? Mr. Seifarth, it looks like you have something on your mind.

Mr. SEIFARTH. Yes, sir. Thank you for the question.

Yes, our company, Voith, participates primarily in these pumped storage hydroelectric projects and they can be from a small scale to a very, very large scale.

For example, just two hours from here is a project called Bath County in Virginia. It's one of the largest pumped storage facilities in the world at around 3,000 megawatts, and it works just on that premise is during off peak hours and it pumps water to the upper reservoir and then during peak demands it releases that water. In addition to that it provides ancillary services to the grid by reacting very quickly to keep the grid stable and secure and reliable for both power and frequency control.

There are advancing technologies that help make this even react faster in milliseconds, as I mentioned. So yeah, those technologies exist. They have been, pumped storage has been around for 100 years. It is well-proven, but it's been able to adapt to be able to support the other generation technologies that have come on board. So, it's kind of like Old Faithful there. It's been able to adapt and support a variety and a good mix for American power generation.

Senator RISCH. What is the fall on the reservoir that you are talking about? What is the——

Mr. SEIFARTH. So this one located——

Senator RISCH. Approximately.

Mr. SEIFARTH. This one located in Virginia is quite high. It's roughly 1,000 feet. And that's one of the larger ones.

There's also many around the country, roughly 42 right now, with a lot more that are viable, but you just have to get through that hurdle of the licensing process.

Again, our company believes in a good mix, a good, diverse mix, not a one-size-fits-all, but certainly hydropower and, in particular, pumped storage must be considered when we talk about a reliable U.S. energy grid. It would be that vehicle that cannot only produce electricity but also store electricity and be able to regulate.

Senator RISCH. I appreciate that.

Anyone else want to weigh in here?

Mr. KATHPAL. Thank you, Senator.

I just wanted to add a comment to provide some contrast to pumped hydro technology because I would like to respectfully disagree with Mr. Seifarth's earlier comment that pumped storage hydro is the only proven form of energy storage.

We found that batteries are increasingly being selected in utility applications at scale with the additional advantages that they can be sited where they're needed, and they can be deployed in a quick timeline.

So, I think appropriate for technology with the type of land disturbance of building a pumped hydro plant, the development and permit timelines are long, but as a contrast we recently deployed the largest battery energy storage system in the world outside of San Diego in a matter of six months.

And that was prompted by a——

Senator RISCH. And what is the size of that? Put that in perspective for me.

Mr. KATHPAL. That's 37-1/2 megawatts and it provides power for four hours.

Senator RISCH. That is potential.

Do you want to respond?

Mr. SEIFARTH. Certainly.

And again, we're here to support a diverse energy portfolio. If we talk contrast we're talking 3,000 megawatts of pumped storage and it can deploy that over the course of many, many hours. Again, the power density is quite high.

So I think there is, there's certainly room for the grid to have stability for all aspects, from very large storage technologies that really can help control and stabilize a large grid to these microgrids and point of use that the battery niche market can definitely fill the hole in the gap.

Plus hydro, like I mentioned, has been around for a long, long time and the closed loop systems are environmentally friendly and reduce the amount of land mass that's required.

In addition to that we have a fleet of 42 pumped storage facilities in the U.S. that are there. They're ready for modernization to help support any other renewables and battery technologies that come on the scene. So it would behoove us to help modernize those existing facilities.

Senator RISCH. I was surprised to hear you mention Virginia. I would assume most of those 42 are in the Western states. Is that right, given the geography?

Mr. SEIFARTH. They spread coast to coast.

Senator RISCH. Really?

Mr. SEIFARTH. You know, obviously, we like a delta, an elevation, but there's Luddington up north. There's facilities out in California, in the Southeast. So it's where we have that topographical differential of anywhere from 400 to over 1,000 feet are prime locations.

Senator RISCH. Thank you.

Thank you, Madam Chair.

The CHAIRMAN. Thank you.

Senator King.

Senator KING. Thank you, Madam Chair. I wanted to thank you for the treats from the Alaska Community Foundation. I'm going to penalize those who don't show up by taking theirs.

[Laughter.]

I appreciate that.

Just first a statement. I want to thank all of you for being here. I want to thank the Chair for holding this hearing, because I think it is one of the most important issues in energy today.

We are moving toward renewables. Of course, the question about renewables is wind, it doesn't always blow. The wind doesn't always blow, the sun doesn't always shine, but renewables plus storage equals baseload.

That's really why I think this is so important, and it's critical to be talking about these issues and how we encourage the development of additional storage technologies.

It seems to me that one of the other things we need is a level playing field. So, for example, if a homeowner has storage in their house along with solar panels, the value of that to the grid should be part of their payment, if you will.

What worries me about the various schemes for net metering and those kinds of things is it's sort of a blunt instrument, and there is an important value to provide to the grid.

I guess what I want to ask—perhaps, Mr. Sprenkle, you are the right guy to ask this question. Are we making the kind of progress in the economics and density of storage that we have made in recent years in solar panels? In other words, are we seeing a significant cost come—down? Because as that cost comes down, the whole world changes.

Dr. SPRENKLE. So, I do think in certain things that we are seeing, like I talked about flow batteries, we are seeing those prices come down to where they're getting closer.

The problem with a lot of these technologies that would work very well on the grid—provide you six hours and longer, eight hours of duration to be able to peak shift the renewables. The problem is there's no intermediate or industry. So lithium-ion came up through commercial transportation and now we're seeing it on grid.

And so, a flow battery, because of the lower energy density, doesn't have that same space. And so, they have to——

Senator KING. In terms of the technology generally, not just of the flow battery, but technology, are we seeing progress? I assume Tesla——

Dr. SPRENKLE. Yes. Lithium-ion prices have dropped dramatically over the last five years, that has enabled a lot of market penetration.

Senator KING. I think another important aspect of this is the—well, let me back up.

In Maine, in your power bill, transmission and distribution cost more than generation. It is more than half of the bill. And most of us who have been in this industry for a long time always think about the cost of generation, you know, whether it is solar, hydro or nuclear, or whatever.

But transmission is a huge cost. Storage enables us to avoid transmission investments, isn't that correct? You are nodding, but the record won't——

Dr. SPRENKLE. Won't show it.

Yeah, so I think in a lot of the, as part of our program we'll go out and work with, you know, to look at the locational value of energy storage. And when we do that——

Senator KING. You are on a peninsula and need to build a new line to get the August peak. If you can do storage down there for a third of the cost, everybody is better off.

Dr. SPRENKLE. Right.

Senator KING. Isn't that correct?

Dr. SPRENKLE. So, we're seeing that now.

We're doing a project in the San Juan Islands in Washington. And Decatur Island is the first, where the transmission line comes in for 14 islands. And that, there's a battery system that's going to be sitting there and most of the benefits from that, and we're still in the analysis part, is going to be the transmission and distribution deferral. Benefits of just them not having to upgrade that system by using that battery.

Senator KING. Mr. Kathpal, do you see that happening?

Mr. KATHPAL. Absolutely.

AES recently partnered with Arizona Public Service, a utility in Arizona, to begin deploying a battery in a small town where demand is growing. The town is 90 miles outside of Phoenix, so the last length of transmission and distribution to it is a 20-mile line that goes through some pretty rough terrain. The utility selected placing a battery at the end of that line as a more economic solution than upgrading the transmission or distribution lines. And they've said that this is at, ultimately, half the cost to the consumer of what would have been the traditional transmission or distribution solution.

Senator KING. You are obviously working with the utility that understands this.

One of the problems, it seems to me, in the long-term that we have to think about is how do we reward utilities for solutions that do not involve building things?

In other words, the traditional model of utility income is a return on investment. So there is an incentive to invest. And if you are doing it for half the price, that utility, theoretically anyway, is losing a significant amount of income because they would have built that line and gotten a rate of return on it and that is good for their shareholders.

So we need to not take income away from the utilities, but to think of other models for their economic performance other than rate of return on investment when, in fact, we can come up with, through storage and other technologies, lower cost investment which would benefit the ratepayers.

I appreciate your being here. And Madam Chair, I really appreciate you having this hearing. This is important stuff.

Thank you.

The CHAIRMAN. It is important stuff. Thank you.

I appreciated the acknowledgment there that when we are talking about storage, you want to have access to a great deal of it, as you noted Mr. Seifarth, and the applicability with the pumped hydro storage.

But I think about the very small villages in Alaska. Again, the smallest, the micro of the microgrids, and how in a place where we don't have interconnection between the communities, it has to be these little, stand alone systems.

The opportunity to go out to the Village of Kongiganak and to see how they have literally taken Chevy Volt batteries and layered them in a little shed outside. That is their battery storage unit, if you will, for the three wind turbines that they have, allowing them to get off diesel generation for, at least, a couple days when the wind is really picking up. Then when it stops we have some backup there. So we need to have it, clearly, at both ends. Recognizing that, I think, is important.

Senator Duckworth, I will let you ask questions. I am going to have another round here, but since you have just come in to the Committee, welcome.

We have a great group of folks here today.

Senator DUCKWORTH. We do, a real good news story, especially for my home State of Illinois.

Thank you, Madam Chairwoman, for convening this very important conversation.

As we have already heard, energy storage holds enormous prospects for a more flexible, cleaner and affordable electricity grid.

In my home State of Illinois, we're not only leading energy storage research and development, we're also manufacturing the technology and we're exporting it. So it is actually creating jobs and bringing money back into the U.S.

One company that comes to mind is a group that emerged from a school project at Northwestern University, SiNode Systems. Today, SiNode is manufacturing battery technology on the South Side of Chicago and exporting it to countries around the world. Their technology is helping electrical vehicles go further and making our cell phones last longer. And trust me, my cell phone needs it. I have a three-year-old, so she's on there all the time.

In addition to entrepreneurs like the folks at SiNode, Argonne National Laboratory is also on the cutting edge of energy storage research.

Dr. Sprenkle, your lab is a member of the DOE Joint Center for Energy Storage Research (JCESR) which is led by Argonne National Laboratory in Illinois. Your collective work has brought the private sector, universities, and the Federal Government together to solve challenges of developing next generation battery technology.

Can you share your thoughts on the need for continued research in new chemistries and materials to address the nation's future energy storage needs?

Dr. SPRENKLE. Yes, thank you for the question.

We are proud to be part of the JCESR. JCESR has really done an excellent job, in terms of advancing the state-of-the-art, in terms of our ability to characterize materials, our ability to predict new material systems.

The goal is eventually these will go into the low-cost systems that can be deployed across the country and hear from multiple applications.

And so, it is really looking at taking a step change, in terms of the base materials cost that we will need and being able to achieve the long lifetimes that we want from these grid-scale assets in there.

Senator DUCKWORTH. Well, what does that mean for consumers, these investments? And especially, you know, my understanding is that the materials that we are looking at now are things that we never would have looked at even 10, 15 years ago as potentially viable.

Dr. SPRENKLE. Right.

So, we're—as we've looked at, you know, distribution and transmission deferral, those are exact savings to consumers, and when we go look at microgrids and systems that could be set in a microgrid, but then called on to reduce peak generation so we don't have to build a new peaker plant, those all go directly into saving the consumers money in this.

Senator DUCKWORTH. Thank you.

As the panel I am sure knows, last week Secretary Perry directed FERC to issue a sweeping proposal to redefine how certain power generators are compensated for their electricity.

API, the Natural Gas Supply Association, and the wind and solar industries have all united against the proposal. Mr. Kathpal, what is AES' position on this?

Mr. KATHPAL. Thanks, that's obviously a good question and something we've been thinking about a fair bit.

I would say that, first of all, there's no market design that's perfect. We agree that resilience is important and certainly we believe that energy storage and other resources have resilience attributes that are not always taken into account, whether it's being valued by power markets or other parts of the energy policy and regulatory world.

That being said, the proposed rule focuses on one resilience attribute, as far as we can tell, which is the onsite availability of fuel. And again, that's a relatively limited view, given the various other resilience attributes that we think storage and other resources bring. Some of those being providing grid stability in the short-term on an operational timeframe, as well as being rapidly deployed in places where power is needed on a planning timeframe.

The good news is that FERC is currently examining some of these issues with respect to storage already within a notice of proposed rulemaking on energy storage issues within the power markets. We're hopeful for developments there as well as for market solutions and policy solutions that would improve the valuation of those resilience attributes.

I would say that the proposed mechanism in the rule you're referencing would be a significant change to U.S. market design and should certainly be subject to public debate.

Senator DUCKWORTH. Thank you.

Does anybody else have a comment or want to make a comment on this?

No one is going there?

[Laughter.]

Alright.

Then I want to follow up a little bit, Mr. Kathpal.

Last year, the Illinois State Legislature passed a law that will invest $750 million in wind and solar initiatives. Those investments will build on an already strong wind and solar industry in my home state. In fact, since we started pursuing investments in wind, we have created 100,000 jobs in Illinois alone, just in wind.

As you mentioned in your testimony, energy storage is a key enabler of renewable integration into the electric power system. In addition to helping wind and solar, are there ancillary benefits to energy storage?

Mr. KATHPAL. Yes, absolutely.

So we believe that in addition to working well with wind and solar, energy storage is great because it's a resource neutral, fuel neutral, flexibility tool so it can be used to provide capacity where a capacity on its own is needed. It can be paired with renewables to lower generation costs, as my company is doing on the island of Kauai, providing 28 megawatts of solar, paired with five hours of batteries at a fraction of what consumers on that island would pay for burning oil.

We have experience in deploying storage in nine U.S. states and six countries, so it seems like in pretty much every supply mix, every regulatory structure, we're finding a business case for energy storage. Sometimes that's ancillary services and in an organized power market, sometimes it's a specific co-benefit of pairing storage with a type of generation and sometimes it's on the infrastructure side with transmission or distribution applications.

Senator DUCKWORTH. Thank you. I am out of time.

Thank you, Madam Chair.

The CHAIRMAN. Thank you, Senator.

Mr. Moores, I do not want to leave you out of this conversation because of what you have brought to the table as we are discussing these opportunities when it comes to energy storage technology.

As I mentioned, we have to be able to have the minerals, the critical minerals, that allow us to lead in these spaces.

You mentioned China and not only pointed out that China has significant quantities of critical minerals, while we, in this country, also have some good supplies. I know in Alaska we are looking with great interest at some of the supplies that we have, but we also recognize that in addition to China having the materials, they have the factories, they are doing the processing, they really are in control of many of the parts of that supply chain.

I think it was you, Dr. Sprenkle, who mentioned the United States and the leading role that we have played with the development of the lithium-ion battery. But Mr. Moores, where do we go if we are in a situation that I have outlined where we are reliant on other nations, for at least 50 percent of 50 different minerals? We are 100 percent reliant on 20 different minerals, nine of which

China is the primary source, and at least 50 percent of another 30 minerals.

In addition to not having the resources here and also relying on China for processing of minerals, how vulnerable does this make us? How concerned are you and others in our ability to continue to lead in these areas as we try to develop these technologies if we do not have these critical minerals?

Mr. MOORES. Yeah, thank you for the question.

I wouldn't be necessarily concerned about every rare mineral or mineral that you can't pronounce or that sounds like a rare mineral because they're used in very high-tech applications. They might be very niche. They're likely to be part of a big growth industry.

I would be very concerned about technologies that are going to be called to the next big industry, energy storage, because that's going to fundamentally alter the car industry, alter sectors. It's going to fundamentally alter the energy space over the next 100 years.

And so, those core minerals, well let's say the battery technology that will be central to that for the next 10 years, 10 to 15, will be lithium-ion batteries. That's because of the cost. It's because of the scale they're being produced. They're going to be produced over the next five years with the rise of these battery megafactories around the world. And so, really, I'd be looking at the four critical raw materials that go into a lithium-ion battery, which are lithium, graphite, cobalt and nickel.

But again, these aren't nickel as a commodity. It's a metal, but it's actually the nickel chemical that goes into a battery, very specialized processing route. Not many people do this.

Of those four raw materials, for batteries, the U.S. imports 100 percent of each. So no mining of these speciality raw materials happens in the U.S., yet, apart from the——

The CHAIRMAN. Explain to me, if you will, because you have used that term now several different times that we need to view these not as commodities, but specialities.

Mr. MOORES. Yeah.

So these are niche—essentially a commodity you would dig out of the ground and you have light pile, for example, of coal and you have a customer that can use that product, pretty much, straight away. It's driven, really, by the supply side, not the customer.

For these raw materials they are, they change per customer. So the lithium that one battery company might get might be slightly different to the lithium that another battery company gets. And these are very specific customers. So really there's a tailoring that happens and a couple of steps of processing, chemical processing, that happens to the raw material. It's those steps that the industry, that countries actually, need to fully understand.

The CHAIRMAN. Because we are not doing any of that processing here, are we?

Mr. MOORES. No, no. For lithium——

The CHAIRMAN. Is most of it happening in China?

Mr. MOORES. Yes.

But for lithium you have two companies. You have Albemarle, which is a U.S. company, and FMC Lithium as well. And they do produce some battery-grade lithium here, but they're not sourcing the lithium from the U.S. For the others, no. Happens in giant graphite, 100 percent in anode graphite, it goes into a battery, is from China.

The CHAIRMAN. One hundred percent of it.

We have some graphite up North that we are looking to develop.

Mr. MOORES. Yeah, there are two areas. There's Alaska, there's Alabama in the U.S., that have been developing resources and it's quite interesting. It's not just the resource, it's the processing that happens to make these battery-grade materials. And that's really where the gap is.

The CHAIRMAN. Is it an issue of investment in the supply chain here in the United States that is holding us back or is it our regulations? I know that from a processing perspective that is a real challenge for us, but is it more on the investment side, in your view?

Mr. MOORES. Yeah, investment would be number one, then regulation, number two.

But I think the investment, as this industry grows tenfold, the battery to lithium-ion battery model grade, tenfold over the next 10, 15 years, then the investment should become obvious. It should, the money should come from somewhere. At the moment, it isn't, but that should sort itself out in a reasonable timeframe. And——

The CHAIRMAN. So you think just increased demand will bring that investment on?

Mr. MOORES. Yup.

The CHAIRMAN. You think that that will marry up here.

Mr. MOORES. Yeah.

I think so. I think at the moment it's all coming from institutions, whether New York or San Francisco or places like this. And they're starting to understand the battery story and how big this is going to be and how disruptive.

But still, the problem is all of these companies that are making, that are building the mines or doing the processing plants, battery-grade processing plants, are also very small companies. Institutions can't invest in them because they end up owning 100 percent and they can't get in and out and do their investment thing. So for now, it's a niche industry going into the mainstream and we're, kind of, stuck in the middle at the moment.

These companies are now looking for help from the industry, from investment and from government, and they're not quite getting it yet.

The CHAIRMAN. Let me ask both Dr. Sprenkle and Mr. Kathpal, are you concerned about the issue that Mr. Moores has raised with the ability to access, whether it's lithium, graphite, cobalt or nickel?

Dr. SPRENKLE. So, yeah, there are concerns about that. We've got active programs looking at developing the sodium replacement for lithium that we can get. It's nowhere near the size of what they're doing in Japan where every major manufacturer is developing an alternative to have a sodium-ion battery, in case they need to, they can plug into their system.

Other materials we're looking at, like with our vanadium flow battery. We're not on the same level of criticality but can we take that to a point where I can make an organic molecule that can be synthesized and perform the same function as that vanadium species, then I'm no longer dependent upon commodity metal at that point to be able to keep that cost structure.

The CHAIRMAN. But how far out is that?

Dr. SPRENKLE. And that's, that is a big challenge to do that, to take that molecule and make it electrochemically active in there and soluble, and stability that we need. But the payoff at the end is that you have something you can control and something that you can design the properties that you want and control, you know, basically how much is made, so——

The CHAIRMAN. Mr. Moores?

Mr. MOORES. Yeah, it's interesting actually that you look at different battery technologies, vanadium flow is one of them. But the reason we could come back to lithium-ion is we just, we follow where the money is.

Thirty-five billion dollars has been invested in these lithium-ion battery megafactories. Now it's hard to understand, but it's true that they're invested without any kind of true understanding of the supply chains that feed them and the minerals that go into these batteries. It's only after they put these grand plants in place they realize we better look at getting our lithium, or lithium prices have gone up four times or nickel is going up double.

And so, really, I guess the point is that the decision, the direction of the industry, has already been made. The blueprint for the next generation of this, the next step of this energy revolution for electric vehicles and for, to a lesser extent, but certainly for utility storage, the decision has been made on lithium-ion.

There's two chemistries actually, there's NCM and NCA, which is a nickel, cobalt, manganese and a nickel, cobalt, aluminum.

But it's the supply chains that are always the last to react because people that plan these things, whether it's VW planning to put ten million electric vehicles on the road or whether it's the battery companies planning to build 15 gigawatt hours worth by 2020, the mine upstream is the last link in the supply chain and the last thought.

It's only recently, because I've been getting these price shocks, they've been going to their customers and they're getting charged three, four times for their lithium hydroxide. That's when they realize there's a problem and these supply chains have to be looked at long-term.

The CHAIRMAN. Well, it is a part of our dilemma here where we are clearly building the interest and demand. We talked about breakthrough technology earlier and most of you said we don't really need a breakthrough. We have the intelligence here and we have the technology. We just need to work to bring down the cost.

Well, if the cost is going to be subject to the whims of China or other nations that hold the initial resource that we need, that is going to make it tough to get to that point where everyone would really like to be.

We are in a situation where we have this foreign dependence. I think about the position that it puts us in because it wasn't too many years that we were talking around this Committee room here about our vulnerability as a nation on OPEC, on nations like Iran, Iraq, and Venezuela, and people that we did not particularly want to be doing business with and our technologies have allowed us to move beyond that.

But I think about the issues that present themselves when we think about the minerals that go into so much of, well, just everything that we do. We do not think about them as part of that supply chain and how it influences the decisions, whether it is for the investors or whether it is for the market that we are trying to grow as we try to reduce the overall costs.

So I appreciate the focus that you bring to the conversation, Mr. Moores, because I think it is an important part of what we are trying to do here. We want to be innovative. We want a breakthrough. We want to get to this point where we can incorporate and integrate all these additional technologies through the use of energy storage.

So much of what Senator Franken wants to do with renewables, and I as well, is going to depend on our ability to get this stuff out of the ground and then be able to process it. So it is something that needs to be talked about, and we are doing the talking here.

Senator Franken, do you want to have the last question?

Senator FRANKEN. Sure, thanks.

Thanks for being here today and talking about storage. Storage, I really think, is an enormous game changer, allowing renewables to be baseload and also to increase grid reliability and resilience.

That is why Senator Heinrich and I recently introduced the Advancing Grid Storage Act to promote research development, demonstration and deployment of grid-scale energy storage systems. The legislation provides dedicated funding for storage systems within ARPA-E as well as creating grant and technical assistance programs to help overcome barriers to deployment.

So I would like to hear from the panel about what barriers you see to the deployment of energy storage systems.

Dr. SPRENKLE. So we tend to look at this as breaking down a long—it's a cost and it's the realized benefits of storage. Oftentimes when we look at the benefits, they're not fully defined and it depends on where the storage is located.

And so, we have 3,000 utilities in the U.S., each with a different asset mix, each with a different operational condition. That value of storage changes in there. And so, that's a challenge to be able to get the planning models and analytical tools so we can go in and determine what that value is.

But also we need to drive the costs down to where it is easy to buy these systems and put them out on the grid, at all levels, whether that's at the home or community or at a substation and have that tiered resiliency.

Senator FRANKEN. Anybody else?

Mr. KATHPAL. Sure.

We find that one of the key barriers to increasing competition and opening access to energy storage is getting it into the planning and procurement frameworks of the utility industry and, I think, Senator Heinrich probably knows this quite well because his state was one of the first to pass a rule at the state utility commission that asks the utilities in that state to look at energy storage as a resource option.

So it would be directly compared to building a new, natural gas-fired, peaking plant before they decide on what their new sources of capacity would be.

And so, that type of analysis when Dr. Sprenkle talks about planning models, that type of integrated resource planning happens in many states of the country. That's how utilities decide what to build next. And we see a need for technical assistance, whether that's to the state utility commissions, state energy offices, directly to the utilities, the regional planning or reliability organizations in getting storage on the menu so that it can be considered, but then also for its benefits to be analyzed comprehensively when those decisions are made.

Senator FRANKEN. And that is something New Mexico did.

Mr. Moores?

Mr. MOORES. Yeah, just to answer the question, the original question, the barrier to energy storage.

Senator FRANKEN. Yes.

Mr. MOORES. I mean, it might sound like quite a simple answer, so I apologize if it is too simple. But it is low-cost availability of batteries, whether they're vanadium flow batteries, lithium-ion batteries, slightly different on the hydro side.

If they're cheap and available then they'll be used. If they're expensive and they're hard to get a hold of, then they won't be used.

With vanadium flow, for example, as a technology, fundamentally much better than lithium-ion for this application, but that uses vanadium pentoxide, very relatively rare compared to this vanadium metal that's produced and dug out of the ground.

If you talk about lithium-ion, if you don't have your lithium, the graphite anode, the nickel chemical that goes in to make a lithium-ion battery, you're not going to have the batteries. You're not going to have energy storage systems that AES have installed on Kauai, for example. And so, it's cheap, low-cost batteries and then in order to get those, it is steady, stable materials, minerals and chemicals that make these batteries. And I think, fundamentally, that depends on everything.

Mr. SEIFARTH. And for our industry it's quite simple. It's valuation and it's policy to put us on a level playing field.

Senator FRANKEN. By policy what do you mean exactly?

Mr. SEIFARTH. So, for example, the process steps that we must go through to even modernize an existing hydropower plant are, I think the best word is cumbersome, time-consuming, laborious. It's years, 8, 10, 12 years in many cases. And utilities just don't have the stomach to invest in something that long with the flip of a coin if it will go forward or not.

Senator FRANKEN. Okay, thank you all.

One last question.

Is there something we can do? If you wanted us to do something to help, what can Congress do?

Dr. SPRENKLE. I think we used the example of the lithium-ion timeline before and that it, you know, we had the materials in the late '70s and it took until '91 to get that material into commercial production and now to get that cost down.

So as we're developing these technologies I can do a step change, in terms of the overall cost and make them common, like has been said, it is that continued focus on developing these and getting them through this to the point where they can be a commercial reality.

That's, I guess, going back to one of those barriers is before the new technologies coming through, it's just that long-term focus on it.

Senator FRANKEN. Thank you, Madam Chair.

The CHAIRMAN. Thank you, Senator Franken.

Gentlemen, thank you all for being here today and for your contributions. I think this has been a good discussion and gives us, as a Committee, something to build on. Again, recognizing the immediate situation in Puerto Rico and knowing that we have opportunities to try to build out more resilient energy infrastructure. We have these opportunities because of what we see coming out of our national labs, the innovations coming out of industry and then we have our good, old, reliable hydro. We sure thank you for that.

But I do think it is important that as a Committee we recognize that as innovative as we can possibly be in these areas, we still come back to the need for more base power. I look at critical minerals as being the true baseload here, because without it we cannot get much of anything else started.

So just keep that in mind, and thank you for, again, your leadership in these various areas. I appreciate that.

With that, the Committee stands adjourned.

[Whereupon, at 12:08 p.m. the hearing was adjourned.]

APPENDIX MATERIAL SUBMITTED

U.S. Senate Committee on Energy and Natural Resources
October 3, 2017 Hearing
To Examine the Status of Energy Storage Technologies, Reviewing Today's Technologies and Understanding Innovation in Tomorrow's Technologies
Questions for the Record Submitted to Dr. Vincent Sprenkle

Questions from Chairman Lisa Murkowski

Question 1: There are many current applications for energy storage technologies in microgrids, which can increase both reliability and resilience. Alaska has been a pioneer in hybrid energy microgrids. Can you please discuss how you see energy storage technologies – both today's technology as well as future technology – enabling the deployment of microgrids to provide continuous power to high value assets?

Answer: Hybrid energy microgrids containing both renewable and fossil-based generation resources have been shown to significantly reduce fuel consumption. Alaska, with almost 200 isolated microgrids reliant on imported diesel fuel, has been at the leading edge of this development for the country. The adoption of energy storage technologies into these microgrids can further reduce costly fuel imports by minimizing the time fossil assets are needed to buffer low periods of renewable generation and maintain a consistent output of power. Today, dispatchable energy storage technologies, like batteries, may be able to economically shift a few hours of renewable generation. New technologies that significantly lower the cost of longer duration energy storage can further reduce the dependency on imported fuel while simultaneously improving the resiliency of the system for extended outages.

Question 2: There is a lot of excitement in the energy storage world about lithium-ion batteries, especially in electric vehicles. There are also other storage technologies that are currently deployed, including pumped hydro, and thermal storage.

a. Dr. Sprenkle, what are the physical limitations of today's energy technologies, in terms of the ability to load shift and cycle frequently?

Answer: Each storage technology has unique physical characteristics that allow them better performance under certain applications, like load shifting. Technologies such as thermal storage are effective at shifting large electrical loads away from periods of peak demand, however, they are limited in their ability to impart electricity back into the grid when needed. Pumped hydro, compressed air, flywheels, and electrochemical systems like batteries all can deliver electricity back into the power grid thereby enabling utilization for a number of different applications. Pumped hydro and Compressed Air Energy Storage (CAES) have been proven effective in providing long duration energy storage for several decades, but are limited in deployment options due to the required geology. Today, most new energy storage deployments on the grid are in the form of battery energy storage and have shown to be economically viable for certain high-value applications such as frequency regulation and demand charge reduction. The flexibility and modularity of battery energy storage can enable systems to be sited at both kilowatt scale residential and community systems and multi-megawatt systems at substations and baseload generators providing a "hierarchy of resiliency" across the entire electricity infrastructure. To achieve widespread deployment of energy storage across the electrical infrastructure, significant advances in understanding and controlling the physical phenomena that dictate the lifetime and costs of these systems will be required.

b. In addition to flow batteries, are there other energy storage technologies that you believe have high potential, like fuel cells, solid state batteries, or small compressed air storage?

Answer: Given the diversity of electric utilities, generation technologies, and pricing across the U.S., certain storage technologies may be better suited than others for certain applications. Today, more lithium ion batteries are being deployed in the grid as their costs fall due to expansion of mobile consumer and transportation sectors. This battery technology is being primarily designed for relatively short-lived applications and may not have multi-decade lifetimes, inherent safety, and costs that newer technologies, designed from the ground-up for grid applications, ultimately have. New battery technologies utilizing water based electrolytes and earth abundant elements offer unparalleled safety and dramatic cost reductions over today's technologies. And while flow batteries do fit within this paradigm, there are numerous other configurations and options that could be utilized. Solid state batteries, in which the organic electrolyte is replaced with a non-flammable solid material, could also improve safety and may be suited for deployment in dense population centers where space is at a premium. Small, modular compressed air or pumped hydro storage may offer smaller scale storage options with utility scale lifetimes. To ultimately enable greater deployment of energy storage, we will need a suite of energy storage technologies to choose from to best meet the unique physical and economic challenges found in each region of the country.

Question 3: FERC recognized the importance of the advent of mass deployment of energy storage technologies with a new Notice of Proposed Rulemaking last year, followed by a policy statement this year. This is something that ENR will continue to track in our oversight role. We have heard testimony about the various grid services that can be provided by different types of energy storage technologies. The industry is grappling with how to properly evaluate and commoditize those benefits moving forward. I believe that our role should be to remove barriers to market for energy storage technologies. As the markets evolve, are there any specific challenges – in terms of rules or regulations – that deserve our attention?

Answer: While science and technology efforts are critical to the continued deployment of safe, reliable and low-cost energy storage, we must also have the capacity to fully understand the value proposition for grid storage under the institutional and regulatory environments currently

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in place. Developing a comprehensive analytical framework for the valuation of energy storage, and other new grid technologies, can enable government and industry stakeholders to work together to assess the benefits and costs of storage while quantifying the financial and technical impart of current policies. With a uniform analytical framework in place, industry stakeholders can utilize the same tools and data sets to evaluate energy storage and more accurately inform policy decisions that could lead to greater deployment.

Question 4: Some see energy storage, and the integration of electric vehicles, as a potential challenge to the current utility business model. How could utilities leverage energy storage technologies within their existing operations?

Answer: Greater adoption of all distributed energy resources (DER), including grid energy storage and electric vehicles, will change the current utility business models. Utilities, in partnership with state and federal agencies like the DOE's Grid Modernization Laboratory Consortium, are developing the analytical tools that can better inform utilities how they can leverage DERs to make their systems more efficient and cost-effective for consumers. These robust analytical tools will ultimately help inform utilities on how to aggregate, control, and value DER assets like storage, to defer capital investments in expensive and limited-use peaking plants.

Questions from Senator Ron Wyden

Question 1: Dr. Sprenkle, I am glad to hear the 2013 grid storage report has helped point you in the right direction. I asked for the DOE to prepare that report as chairman of ENR.

On the topic of cost competitiveness, could you offer an opinion on how a significant drop in the cost of storage might lead to more rapid deployment of storage on the grid?

Answer: Today energy storage accounts for a little more than two percent of the 1,070 gigawatts of peak generation capacity of the nation, with 98 percent of that energy storage accomplished by regionally isolated pumped hydro storage. To increase the amount of dispatchable stored energy capacity, the costs of storage systems must further decrease to make them viable for a majority of the utility class services. Falling cost of lithium-ion technology over the past 6-plus years have enabled initial market penetration for some of the higher value grid services like frequency regulation, however, an additional four to five-fold decrease in costs will be required to enable ubiquitous deployment of the technology.While we focus most research and development on reducing the installed capital costs (dollars per kilowatt hour) of storage, we must also emphasize the impact of device lifetime, round-trip efficiency and other parameters on our ability to quantify the cost of electricity that passes through the storage device in its operational life. While individual targets vary, energy storage systems capable of being installed at $100 per

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kilowatt hour with an estimated lifetime of ~8,000 cycles at 75 percent round-trip efficiency should enable storage to achieve parity with other grid resources.

What would be required to achieve this drop in cost?

Answer: To achieve the desired cost, lifetime, and efficiency needed to ensure wide-spread deployment of storage technologies will require significant advances in R&D and lower cost manufacturing processes. Prices for lithium ion related technologies are expected to continue to fall but the target application markets for these technologies only require 1,000-1,200 cycles, making the cost of ownership for a majority of grid application unattainable. New breakthrough technologies, based on earth-abundant and intrinsically safe materials, need to be developed and validated to operate over the 8,000 cycles desired. Advanced manufacturing architectures must be developed that enable new technologies to compete economically with existing storage technologies while supporting the reliability of the new technologies. These efforts can ultimately lead to the development of new technologies that can meet the both the cost and technical requirements for a majority of the grid storage applications.

Question 2: In your spoken testimony, you highlighted how long it took for lithium-ion batteries to become cost competitive. I recently introduced a bill, S.1876, that would authorize the Department of Energy funding to reduce the cost of energy storage through research, development, and demonstration.

Do you think new R&D investment will accelerate the deployment of energy storage?

Answer: R&D investments across the spectrum of energy storage technologies are needed to accelerate the deployment of energy storage. Accelerating the deployment of energy storage requires a focused effort on improving the benefit-cost relationship for storage such that it is competitive for a majority of grid applications and R&D can play a critical role in both reducing the cost of energy storage and assessing the net benefits it provides to the grid. New materials and manufacturing platforms can reduce the cost of the storage device and associated power electronics while uniform safety requirements and controls reduce the cost installation and operation. New analytical tools must be developed with sufficient fidelity to accurately capture both the locational and system benefits of energy storage and enable industry stakeholders to utilize common methodologies to assess the value of energy storage. Analysis of field deployed energy storage systems are critical to ensuring the fidelity of these tools and to developing end user confidence in the technology.

What else can be done at the federal level to accomplish this goal?

Answer: As mentioned in my testimony, the 2013 Grid Storage Report provides an excellent roadmap on the challenges facing grid scale energy storage. Continued and accelerated efforts on the development of cost-competitive technologies, improved safety and reliability, standardized

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valuation methodologies, and industrial acceptance can, and will, lead to greater adoption of energy storage. New design tools and characterization techniques can better inform the materials discovery process and accelerate the innovation process. Common manufacturing platforms applicable to entire classes of storage technologies can speed the development time between innovation and validated system-level performance. New planning and design tools for utilities and regulators that can accurately determine the optimal size, location, and net benefits of storage deployments can greatly reduce institutional uncertainty on the value of energy storage.

Question 3: In your testimony, you said that storage must be cheap, long lasting, and safe.

What R&D opportunities do you see for energy storage systems that could have superior cost, performance, and safety compared to today's lithium-ion batteries?

Answer: As mentioned previously, the falling cost of lithium-ion technology over the past 6 plus years has enabled initial market penetration for some higher value grid services like frequency regulation. And while costs of lithium ion technologies may continue to decrease, there are significant limitations in lifetime and safety that may make the cost of ownership for a majority of grid application unattainable. Certain types of redox flow and sodium-based batteries have shown the decadal lifetimes desired for grid applications but are not suited the mobile and electric vehicles markets that are supporting mass production of today's lithium-ion batteries. Other battery technologies have shown tremendous potential for ultimate costs lower than lithium-ion but have had difficulty reaching the necessary level of maturity to realize these costs. Integrated R&D efforts aimed at both reducing the costs of the constituent components and providing an accelerated pathway to commercial scale production and validation offers the greatest opportunity for the cost, lifetime, and safety benefits of these next generation technologies to be realized.

Question 4: Dr. Sprenkle, as the penetration of renewable resources increases, batteries of many types will become more valuable. My bill, S.1876, has a call out for a focus on relatively underdeveloped and potentially transformative storage technologies.

What types of energy storage technologies would you suggest should be part of that focus?

Answer: There are a significant number of energy storage technologies, both battery and non-battery based, that are currently underdeveloped but with the potential to transform the stored energy capacity of the grid. While it would be difficult to address every R&D barrier for every potential energy storage technology, there are certain technologies that share some commonality of challenges and can benefit from a focused R&D effort. As an example, new battery technologies which utilize water based electrolytes and earth abundant elements offer unparalleled safety and the potential for significant cost reductions over today's technologies. The flow battery technologies being developed at PNNL are just one example that falls within this category. The water based electrolyte mediates the flammability concerns associated with

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the organic electrolyte used in lithium-ion batteries and utilizing earth abundant elements such as sodium, iron, zinc, and water soluble organic materials for the electrochemical reaction ensures a continuous availability of low cost materials. These technologies would all share common materials and performance characteristics that could enable them common system components thereby reducing the costs for all. Other energy storage systems could be grouped similarly based on common characteristics and an overarching roadmap developed that would facilitate greater adoption of these transformational technologies.

Questions from Senator Mazie K. Hirono

Question 1: Hawaii's net metering program for rooftop solar ended in 2015, leaving new rooftop solar customers with a program that effectively encourages them to store the excess power from their solar panels, if they can afford to do so, since customers are not paid for any excess energy returned to the grid. Affording such storage systems remains a challenge for many people. In your view, which current or emerging storage technologies have the greatest potential for use by residential customers with their own renewable power, and do you have projections for the costs of such technologies?

Answer: While the costs of energy storage technologies have dramatic decreased over the past 6 plus years, it is still difficult to develop a reasonable return on investment for residential solar and other renewable energy storage in the absence of incentives or significant demand charges. It is unlikely that we will see continued significant price decreases in lithium-ion technology as the manufacturing process is quite mature at this point. During the same time frame, vanadium redox flow batteries have kept pace with lithium ion cost reductions while having less than 1/1000th of the manufacturing capacity. As such, future advances in flow, zinc, and iron based battery technologies may ultimately enable residential solar and other renewable energy storage to deliver a shorter-term return-on-investment independent of incentives or elevated demand charges.

Question 2: Are there current trends or future projections that lead you to think residential storage technologies will more broadly be in the form of an electric vehicle connected to the home or a stationary home storage system?

Answer: Electrical vehicles play an important role in the suite of distributed energy resources (DER) and must be considered both as a load and potential supply to the system. For areas like Hawaii, with a high penetration of rooftop solar, stationary energy storage may offer significant advantages over an electric vehicle connected to the home. First, the daily transportation requirements make it difficult to synchronize peak generation of solar with availability of the car's battery system. A second issue involves the use of the vehicles to provide services back to the home or grid as we do not currently know how much impact these services would have on

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the lifetime and hence, the warranty, of the battery. Stationary energy storage systems would not have the same issues and could see broader application as costs fall.

Question 3: In June, the Natural Energy Laboratory of Hawaii, Hawaiian Electric Light Company, and others announced their plans to install an advanced flow battery using the element vanadium, to test its ability to provide long-duration energy storage in a warm weather environment. DOE's Office of Electricity and the Sandia National Laboratory offered expertise, coordination, and financial support in helping this project happen. Could you please elaborate on what research and demonstration work remains to be done to determine how to best use storage with high levels of solar and other variable renewable power on the grid?

Answer: Energy storage demonstrations efforts, like the deployment you mention, are being supported across the country by the DOE's Office of Electricity Delivery and Energy Reliability to better understand the regional variations in benefits provided by energy storage. Hawaii, with high levels of solar, warm climate, and unique system constraints, offers a significantly different use case that can better inform the valuation models being developed for energy storage. Ultimately, the data gained from these deployments can be used to create an analytical planning framework in which the value of energy storage can be accurately determined based on the local system characteristics. Additionally, deployments involving new storage technologies, like the vanadium flow battery, provide technical validation of the life-cycle cost, performance, and safety of the system while enabling the lessons learned from these demonstrations to be shared across the entire stakeholder community.

Questions from Senator Catherine Cortez Masto

Question 1: I'm curious about where you believe private sector research and development dollars in the energy storage sector are going to be allocated—as there are a variety of technologies in this sector—including batteries, fly wheels, thermal storage, compressed air storage, and super capacitors.

Answer: There are a few in the private sector making investments in longer-term storage options, however, with an the extended timelines required for market entry of these technologies most private sector research on grid scale energy storage has focused on systems integration and controls to meet the current market opportunities utilizing commercially available lithium-ion technologies. This battery technology has been primarily designed for relatively short-life mobile and transportation applications and may not have multi-decade lifetimes, inherent safety, and costs that newer technologies, designed from the ground-up for grid applications, ultimately have. New battery technologies utilizing water based electrolytes and earth abundant elements offer unparalleled safety and the potential for dramatic cost reductions over today's technologies. To ultimately enable greater deployment of energy storage, we will need a suite of energy storage technologies to choose from to best meet the unique physical and economic challenges found in each region of the country.

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Question 2: What services could energy storage conceivably offer to the grid over the next decade? And are those research and development sector dollars properly aligned? If not, what could Congress do to help?

Answer: The 2013 edition of the DOE/Electric Power Research Institute Electricity Storage Handbook, developed in coordination with the National Rural Electric Cooperative Association, describes eighteen different services where energy storage can be used to support the generation, transmission, distribution, and behind-the-meter needs of the grid. The 2013 DOE Grid Storage Report further identified four critical challenges that must be overcome to enable storage to be viable in these applications, namely the development of cost-competitive technologies, improved safety and reliability, standardized valuation methodologies, and industrial acceptance of the technology. Since then, DOE research and development efforts have focused on addressing these barriers while simultaneously engaging industry stakeholders in advancing the deployment of energy storage. For your convenience I have enclosed the Electricity Storage Handbook and the Grid Storage Report with these questions for the record.

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Questions from Chairman Lisa Murkowski

Question 1: There are many current applications for energy storage technologies in microgrids, which can increase both reliability and resilience. Alaska has been a pioneer in hybrid energy microgrids. Can you please discuss how you see energy storage technologies – both today's technology as well as future technology – enabling the deployment of microgrids to provide continuous power to high value assets?

Answer 1: Unlike most other grid infrastructure, battery-based energy storage provides grid operators, including microgrids, with the unique ability to store excess electricity and deliver it when and where it is needed. This enables microgrids to island from the larger grid if needed, store and deliver as much of their generated energy as possible to service critical industries such as hospitals or can be connected directly to the grid to provide reliability and flexibility if generation assets elsewhere go offline. Storage-enabled microgrids can also provide "black start" services – providing the external power needed to restart electric power stations or portions of the grid after a partial or complete shutdown.

Question 2: FERC recognized the importance of the advent of mass deployment of energy storage technologies with a new Notice of Proposed Rulemaking last year, followed by a policy statement this year. This is something that ENR will continue to track in our oversight role. We have heard testimony about the various grid services that can be provided by different types of energy storage technologies. The industry is grappling with how to properly evaluate and commoditize those benefits moving forward. I believe that our role should be to remove barriers to market for energy storage technologies. As the markets evolve, are there any specific challenges – in terms of rules or regulations – that deserve our attention?

Answer 2: As I mentioned in my written testimony to the committee, at the federal level, we are pleased to see the proposed rulemaking from the Federal Energy Regulatory Commission that would provide fair and equal access for storage resources to wholesale power market products and services. We are also pleased to see FERC provide the direction that storage resources providing a transmission function can seek cost recovery through cost-based and market-based rate structures. We believe these are important policy initiatives at FERC that can create lasting wholesale market changes that fully value the unique capabilities that storage brings and to encourage consideration of storage use for infrastructure needs.

Question 3: Some see energy storage, and the integration of electric vehicles, as a potential challenge to the current utility business model. How could utilities leverage energy storage technologies within their existing operations?

Answer 3: Utilities across the United States are already leveraging energy storage within their existing operations. In the decade that we have been developing energy storage solutions for utilities in six countries, we have deployed systems ranging from 15 minutes to 4 hours in

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duration. In shorter durations, energy storage can regulate mismatches between energy supply and demand on the grid on a second-by-second basis, giving operators enough time to rebalance the system. In longer durations, energy storage can provide capacity that enables utilities to better integrate renewable generation, maintain system reliability and reduce the need for more fossil fuel peaking power plants. Storage can also in certain cases help utilities defer investments in a variety of fundamental, single-function grid assets like wires, poles, transformers and substations, and in the process help utilities get the most value from the transmission and distribution lines they already own and use.

Questions from Senator Ron Wyden

Question 1: Mr. Kathpal, I am also concerned about the delay of the FERC Notice of Proposed Rulemaking on storage as you noted in your written testimony.

In the case where FERC does not move swiftly on this issue, I wonder if you have any suggestions about what could be done to ensure energy storage technologies are valued properly and get a fair shake?

Answer 1: Integration of energy storage resources provides various benefits to the grid. However, while some of the benefits can be monetized through wholesale products and services, there are several categories of benefits that our existing wholesale power markets do not compensate fully. As an example, existing thermal generation plants run more efficiently with energy storage, which leads to reduced emissions. Energy storage also enables traditional generation facilities to start up and stop less frequently, reducing maintenance and fuel costs, as well as reduces curtailment of 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 2: Mr. Kathpal, as the penetration of renewable resources increases, batteries of many types will become more valuable. My bill, S.1876, has a call out for a focus on relatively underdeveloped and potentially transformative storage technologies.

What types of energy storage technologies would you suggest should be part of that focus?

Answer 2: We believe that lithium-ion battery chemistries are fairly mature and private capital from large battery manufacturing companies can move them forward with respect to achieving scale and further reduction in costs. Government should continue funding R&D on other early-stage battery chemistries that have the potential to achieve greater capabilities.

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The national labs, through the Department of Energy, are doing a great job in advancing the modeling and visualization of benefits that energy storage brings to the grid. These are complex analytic simulations that require the use of state-of-the-art power market models and a high degree of computational rigor. We also believe that the government should encourage and increase funding for the DOE and labs to continue this work. This is a critical piece of commercialization because it provides a strong analytic base to looking at costs and benefits of deploying energy storage for specific applications.

Question 3: In your testimony, you highlighted an AES project with Arizona Public Service to install a battery in a small town outside of Phoenix in lieu of transmission upgrades. You said your project reduced the costs to consumers by half.

What other parts of the country do you see as having potential for similar projects?

Answer 3: Much of the nation's electric grid is in need of modernization, whether to keep up with load growth in specific areas, or to provide service more efficiently. Utilities could deploy energy storage projects like the one we are building for Arizona Public Service across their service territories to defer or in lieu of new transmission or distribution infrastructure investments, which typically provide far more capacity than is needed for projected load growth.

As mentioned in my written testimony, in a number of cases, energy storage enables utilities to defer or avoid entirely investments in a variety of fundamental, single-function grid assets like wires, poles, transformers and substations, and in the process, get the most value from the transmission and distribution lines they already own and use. Adding reliability to its distribution network is what originally led Arizona Public Service to work with AES on its first two projects, adding reliability on its distribution feeder in neighborhoods with high adoption of intermittent solar.

Question from Senator Mazie K. Hirono

Question: Hawaii has set the goal of getting 100% of its electricity from renewable sources by 2045, and energy storage will play a key role in achieving that goal. As you mentioned during your oral testimony, AES partnered with the Kauai Island Utility Cooperative to develop a 20 megawatt PV solar system with a 20 megawatt energy storage system. Can you please explain the cost savings or other benefits that you expect the project to bring to Kauai?

Answer: On island grids like Hawaii's, the cost savings from systems like AES' 28 MW solar and 20 MW 5-hour storage system are derived from reduced fuel use for the island's current baseload oil-fired generation, which help reduce electricity rates for its customers. For power delivered from the solar-plus-storage system, KIUC will pay AES less than its recent fuel costs for its existing oil-fired generators (see attached chart).
[SOURCE: http://kiuc.coopwebbuilder2.com/sites/kiuc/files/PDF/rates/2017-09-perkwh.pdf

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Questions from Senator Catherine Cortez Masto

Question 1: What are the largest reasons the private sector is choosing to make investments in energy storage?

Answer 1: As mentioned in my written testimony, energy storage solves three problems at once for both utilities and independent power producers. Energy storage lowers costs to utilities and their customers by avoiding the need to build new gas-fired peaking power plants, and by avoiding or deferring transmission and distribution infrastructure needs. It can be built in right-sized increments rather than the typical lumpy investment profile where large generation or grid assets are built – often overbuilt – in anticipation of future demand growth that, with increases in efficiency in generation, delivery and demand, is increasingly uncertain. Energy storage also enables utilities and power generators to operate existing generating assets and transmission and distribution lines more efficiently. Energy storage is also fuel-agnostic, meaning utilities can charge their facilities with the lowest-cost energy sources. Lastly, storage has additional advantages that make it faster and easier to permit, site and enter commercial operational, including no associated water use, no direct emissions that impact local air quality, no need for fuel infrastructure like natural gas lines, and does not need to be co-located with generation assets.

Question 2: In terms of deployment, have utilities been most interested in deploying energy storage to help meet peak energy needs? What are other factors have been driving investment?

Answer 2: Utilities have been increasingly interested in deploying energy storage to help meet peak energy needs, notably in California but with other states now considering storage as a replacement for traditional generating assets like natural gas peaking plants. The rapid growth of renewable generation has driven utilities to consider storage to provide for local capacity reliability needs.

Utilities are also increasingly looking at application of storage on the transmission and distribution system for increasing reliability and efficiency of the system. Lastly, as noted in my written testimony, storage can add resilience and protect electric grids during extreme weather events, helping communities to get power back online faster following crises. Many communities that weathered storms like those experienced in September of 2017 are now looking to invest in storage to support their grids as a hedge against future weather events.

As mentioned in my written testimony, the Dominican Republic's grid operators ordered our colleagues at AES Dominicana to keep online and operational during both Hurricanes Irma and Maria its two 10 MW, 30-minute duration Advancion energy storage arrays at its Andres and Los Mina Dominican Power Partner facilities. The two arrays, completed in February and May of 2017, were operated from one of Dominicana's thermal plant control rooms and remotely monitored by the AES Energy Storage team to ensure proper operation and to provide the local operators with remote assistance if required. As each storm struck, power lines were damaged, distribution lines were disconnected in high-risk areas, and almost 40 and 55 percent of the generation assets on the island were forced offline, respectively, putting additional stress on the system. To maintain grid frequency during hours of volatile fluctuations during each storm, both energy storage arrays performed more than double the amount of work as normal, which helped keep the Dominican grid operating as the storm passed. The additional power output delivered by the energy storage arrays was equivalent to instantaneously adding a thermal power plant of approximately 30 MW to the grid.

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BENCHMARK MINERAL INTELLIGENCE

Monday 30 November 2017

Questions from Chairman Lisa Murkowski

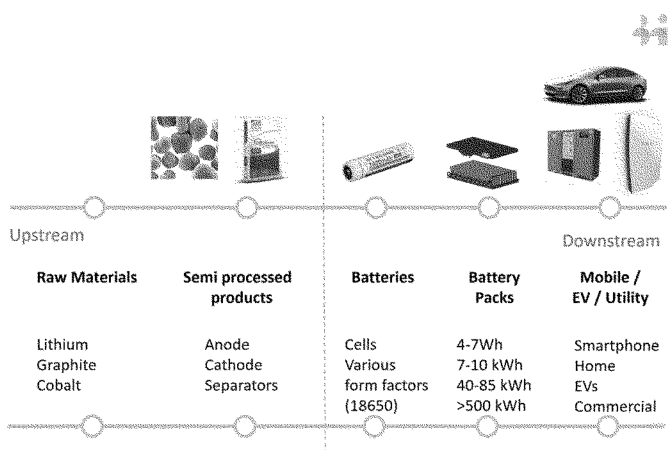
Question 1: It is widely known in the mineral world that China has a monopoly on critical minerals. The United States imported 100 percent of 20 different minerals in 2016, nine of which China was the primary source, and at least 50 percent of another 30 minerals. But, I am also concerned that China is attempting to control other parts of the supply chain, like the factories which produce batteries.

a. What threats does this foreign dependence, especially on China, pose to the United States?

In summary, those that control the lithium ion battery supply chain will control the long term future of the auto and energy storage industries.

Foreign dependence on mined mineral concentrates and, particularly, the battery grade speciality chemicals will undermine US competitiveness in electric vehicle and utility energy storage industries.

This poses quite a few threats along the supply chain. The main links are as follows:



China does not control the lithium and cobalt industries from a raw materials perspective.

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China imports over 90% of its lithium, the vast majority is spodumene raw material from Australia that is chemically processed within its borders into battery grade material. However, China's domestic lithium resources – both brine and hard rock – are nowhere near the grade to commercialise to a significant scale.

The US also imports the vast majority of its lithium from Chile and Argentina and has a small brine operation in Silver Peak, Nevada. However, the US has a great opportunity to build up its own lithium mining operations in Nevada (brine, clay) and North Carolina (hard rock). The US, like China, does have battery grade processing knowhow and technology through the likes of Albemarle, FMC, extraction technology developers in Nevada and new developers in Alberta.

China's strangle hold is on the battery grade processing of spodumene rock. It has become the leader in this and is now moving this technology outside of its borders to Australia. One such $1bn project is being built by Sichuan Tianqi in Kwinana, Western Australia.

These Chinese chemical converters - Sichuan Tianqi and Ganfeng Lithium being the largest - have also been investing in resource assets outside of China (Australia, Argentina, Canada, Europe) over the last 7 years. In the last two years this investment push has intensified especially in Canadian company Lithium Americas and most recently, other Australian hard rock assets.

Lithium is an area where the playing field with investment into new mines and extraction technology could be levelled but at present it is in the favour of China.

It is a similar situation with **cobalt** where China imports 100% of its supply, the majority of which is from the Democratic Republic of Congo. However, China controls the bulk of capacity and knowhow in the battery grade refining stage – an area where the US has very limited exposure and control.

Supply of cobalt from supply security and ethical sourcing / corporate social responsibility perspectives is a significant risk.

Graphite – as the largest input raw material into a lithium ion battery – is also a significant risk to the US from an anode perspective. Flake graphite is the precursor to make lithium ion battery anode materials and the US has zero flake graphite mining capacity and zero natural anode processing capacity. The US can make smaller quantities of synthetic graphite anode, however, the hyper growth in the lithium ion battery market means the US will need to source from China to secure the required volumes.

Much like lithium, without steady and high quality supply of graphite anode, lithium ion batteries will not be produced and battery supply to the auto and energy storage industries will be stifled.

Some foreign dependence threats to consider:

> Trade taxes or embargoes on battery raw material supply from China in favour of value added production of cathodes, anodes or finished lithium ion batteries

> US consumers of lithium, graphite, cobalt and nickel are at the mercy of other political regimes such as the stifled supply of lithium from Chile over the last 3 years

> Corporate social responsibility issues with cobalt and graphite is a significant risk to large US public companies like Apple and Tesla; if these input raw materials into a lithium ion

battery are found to be from illegal, unethical sources (polluting, human rights violations), or banned jurisdictions (North Korea) then the reputation and investment into these large Silicon Valley players could be badly damaged

> Favouring of Chinese lithium chemical convertors for new supply: The US does have battery grade processing facilities in North Carolina via Albemarle and FMC but not yet the capacity to fuel an energy storage revolution; China is presently doubling its capacity of battery grade lithium carbonate and hydroxide production and investing cash into the upstream supply chain. This means as large auto manufacturers secure their supply chains, Chinese chemical producers will be first in line.

> Securing flake graphite precursor supply: US has no active flake graphite mines - the precursor to anode material - and is reliant on primary sources, China and Brazil. While these have provided stable sources of flake graphite for the US, China is cutting back its mining activities and this could starve the US of flake raw material long term, particularly in relation to the battery industry. Brazil poses less of a risk but is historically slow on expanding production.

b. What advantages will China have if they control not only the supply of minerals, but the processing of minerals?

When you focus on the upstream portion of the lithium ion supply chain, these is no doubt that those that control the battery grade processing step - both in the knowhow and the capacity - will hold the sway of industrial power.

Those that control the resources will have a major say but this is secondary to the processing knowhow which allows these materials to be applied into the lithium ion battery industry. It is important to note that we are dealing with a speciality chemicals industry rather than a commodity and therefore each customer receives tailored product and works with their suppliers for long term benefit.

China presently has 60,000 tonnes of lithium chemical conversion capacity rising to 200,000 tonnes in the next 4 years. Sichuan Tianqi is also investing in offshore capacity in Australia in a A$800m, 48,000 tonne facility in Kwinana, Western Australia.

c. China has lower environmental standards for mining than the United States and has lower labor costs. Assuming the United States can't compete in these categories, in what categories can we be competitive – for example energy costs and processing technology superiority?

Technology is the strongest assets for the US. New techniques to extract and process lithium more efficiently can change the economics of the whole supply chain from mine to market.

Technology in creating new Cathode formulations will also directly impact the volume and selection of minerals used in batteries.

And finally, long term, technologies to develop new batteries for a post lithium ion world can sway the balance of industrial power for a post 2030 world in favour of the US. The most promising is solid state but this is far from a commercial reality. At Benchmark, we believe advanced lithium ion is the next successor to lithium ion. What this means is nano engineering the cathode and anode to increase capacity of the battery.

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Question 2: You mentioned in your testimony the potential to develop minerals in the United States.

a. What is our mineral potential in the U.S.?

Very strong, especially in Nevada (lithium brine and clay), Alabama (graphite), Alaska (graphite), North Carolina (lithium hard rock).

While some of these resources may not be the highest grades, US technology and innovation can circumnavigate this.

b. Of the four that you listed – lithium, graphite, cobalt, and nickel – which ones can we produce here?

Graphite, lithium, cobalt and nickel. The US has some strong resources for all of these key battery raw materials. The critical factor will be to develop the battery grade refining step in tandem with the resources, however. This is more difficult.

For lithium ion batteries, the US needs to get out of a commodity mindset and into a speciality chemicals one and help them go from the niche to the mainstream.

c. How can we bring more investment on all ends of the supply chain to the United States?

> Examining mining permits – across the board permitting is a major issue for new mines in the US; It is worth looking at Quebec or Ontario as a template for some states.

> Regular discussion on a Senate level about these key raw materials will help bring non-commodity funds into the space

> Creation of a International Materials Agency – as proposed by David Abraham – would be the ideal forum for this regular discussion to take place and encourage industry to take action

Question 3: Your testimony focused on the use of lithium-ion batteries in electric vehicles, and it suggests a risk for price increases in the minerals needed for battery production, based on a projected increase in demand for lithium of a factor of ten by 2030.

a. **Are we talking about doubling the price of an electric vehicle, or something significantly less? What is the scale of the impact and what is the likelihood of price increases stalling out demand for electric vehicles?**

While raw materials are 60% of the cost of a cell, the cost of the battery for the vehicle is much lower.

For example, lithium has gone from 3% of the cost of a battery cell to 7% with the price spike. However, the cost of a lithium ion cell – through mass production and squeezed margins for battery makers – has fallen to $140/kWh. The price impact on a $50-80,000 vehicle is negligible and well under 1%. And the auto makers and battery producers are absorbing this impact for now.

The reality is that these price spikes only last for a 1-3 years until new supply enters the market. The price shock will also benefit the EV industry long term as its forcing investment and existing businesses to change their blueprints for an EV future.

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b. We know that lithium-ion batteries are used in many other applications, including in the defense industry. If the demand increases as you expect, what will happen to the other technologies that also require lithium? Will we still be able to meet the demand for those sectors?

In the medium term 3-5 years, the situation will no doubt cause disruption to existing markets for lithium and other smaller battery applications outside of lithium ion cells for EV and stationary storage.

Long term however (>5years), investment into new supply will benefit all users of lithium and could indeed spark growth in these other markets such as lithium aluminium alloys for aerospace.

Ultimately, it's in the interest of the suppliers to maintain their customer base as this leads to a healthy stable business.

Question from Senator Ron Wyden

Question: Mr. Moores, I understand that the life cycle and environmental safety of batteries is something that needs to be kept in mind as the storage industry grows.

What would you suggest should be done at the federal level to address this problem?

Creation of an International Materials Agency – as mentioned above – would also be a great addition to this issue.

Energy storage is the major megatrend that will define the next generation. The supply chains should be seen on the same level as the oil and gas supply chains. And a regular professional forum which includes federal involvement and industry experts would solve this issue and encourage industry to take a bigger role.

I would suggest an annual gathering in Washington to discuss all issues – from the international state of play to policy to investment. Benchmark Mineral Intelligence would be more than happy to lead such an initiative from an industry perspective.

Questions from Senator Luther Strange

Question: Mr. Moores, in your testimony you mention two graphite companies (one in Alabama and one in Alaska) seeking to mine and process flake graphite for battery grade material. Can you elaborate more on where graphite is currently being sourced and on potential strategic advantages for the U.S Department of Defense?

The US is sourcing its natural graphite from China and Brazil.

a. Is it possible North Korean graphite could currently be finding its way into the U.S. supply chain?

North Korea does produce flake graphite concentrate in small amounts. The trade route of this most commonly via the north of the country into a very famous graphite producing province of Heilongjiang.

This is where most of China's flake graphite is produced and it is also a hotspot for lithium ion battery anode production.

So while the volumes and probability is on the lower side, there is a possibility that North Korea graphite could be in the anodes that are used in Asia lithium ion batteries. In turn these are the batteries that Major US consumers purchase. So there is a chance that North Korea graphite could be in these cell phones, tablets, laptops and EVs.

b. Can U.S. graphite compete with China on cost? With consistency and quality? Environmental footprint

From a value added products perspective I believe the US can. There are many large graphite specialist companies in the US that have taken advantage of low cost raw material from China to process into higher value products. For the battery anode industry there is a huge opportunity to become a leading supplier of this critical lithium ion battery component which at the moment is dominated by China.

For lithium ion batteries, producers require a very high quality and constant product. These are nano engineered battery raw materials that require specialist knowledge which does exist in the US.

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Questions from Chairman Lisa Murkowski

Question 1: FERC recognized the importance of the advent of mass deployment of energy storage technologies with a new Notice of Proposed Rulemaking last year, followed by a policy statement this year. This is something that ENR will continue to track in our oversight role. We have heard testimony about the various grid services that can be provided by different types of energy storage technologies. The industry is grappling with how to properly evaluate and commoditize those benefits moving forward. I believe that our role should be to remove barriers to market for energy storage technologies. As the markets evolve, are there any specific challenges – in terms of rules or regulations – that deserve our attention?

Answer: We agree that there is legislation that can help such as: H.R. 2880, Promoting Closed-Loop Pumped Storage Hydropower Act; S.1455, Energy Storage Goals and Demonstration Projects Act; S.1460, Energy and Natural Resources Act of 2017; S.1851, A bill to require the Secretary of Energy to establish an energy storage research program, demonstration and deployment program, and technical assistance and grant program, and for other purposes; S.1876, A bill to direct the Secretary of Energy to establish a program to advance energy storage deployment by reducing the cost of energy storage through research, development, and demonstration, and for other purposes; S.1868, A bill to amend the Internal Revenue Code of 1986 to provide tax credits for energy storage technologies, and for other purposes.

We generally feel that reducing the barriers will help make the technology accessible to the market. Barriers and artificial stimulus of certain technologies are not helpful to a market that needs to develop for the long term.

Despite providing grid stability and flexibility, paving the way for intermittent sources of energy to be added to the grid, and enabling the grid to work reliably and efficiently, energy storage development continues to lag behind demand. Unfortunately, there is no mechanism to accurately price these services on the market. If they aren't priced or valued correctly, storage won't get built until it's too late and our grid becomes unstable.

We're encouraged that FERC is taking a closer look at these challenges, as is DOE through its grid study. We do think there are strong pumped storage hydro pilots and R&D programs that should be supported. As I stated in my written testimony, streamlining the licensing process for hydropower will also have a positive impact on pumped storage hydro development, as would re-instating the production tax credit for hydropower (as it has been for wind, solar, etc.). The regulatory issues that slow hydropower development have a significant impact on pumped storage. This committee has done great work on many of these fronts and we encourage you to continue that valuable work.

Question 2: Some see energy storage, and the integration of electric vehicles, as a potential challenge to the current utility business model. How could utilities leverage energy storage technologies within their existing operations?

Answer: As you know, we are an OEM for generation equipment and pumped storage hydro and would recommend that you direct this to the fully vertically integrated utilities that control the path and flow of

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energy from generation to end users, They can provide feedback on where the most value can be generated by inserting and modernizing various storage technologies within their own operations.

Pumped storage hydro technologies provide bulk storage, various degrees of rapid response, base load, inertia, reserves, blackstart capabilities, frequency control, etc., all of which have value in one form or another in an electricity system. As mentioned in the previous question, the valuation for these items is not clearly defined which makes building a business case around many of these technologies very difficult. Improving the clarity and consistency of the valuations nationally or regionally will go a long way toward improving the implementation of these technologies within existing utilities.

The very basis of this question speaks to those challenges with pricing storage in general. There is no doubt that utilities face challenges associated with an evolving energy landscape, and storage is a big part of combatting those challenges. The expansion of electric vehicles will require even more flexibility in the power generation supply.

Question 3: Your testimony mentions pumped storage as a storage resource, but in many respects, a traditional dam on a river also can provide the power grid with many of the services provided by pumped storage. Can you describe the similarities and differences between traditional hydro and pumped hydro in relation to grid operations?

Answer: In generating mode, both types of power plants use the water head difference to produce electrical power and both technologies can avoid curtailment of wind and solar (in case of run-of-the-river within the river level limits).

There are many differences, however, including:

- Run-of-the river power plants cannot store bulk energy since the river flow has to be maintained in certain limits and there are no pumps available. Therefore, the ancillary services are limited.

- The produced energy from a run-of-the river power plant is a pure function of the river water flow and its head. The electrical power is not really dispatchable, but it can be reduced (to zero if necessary). Unfortunately, run-of-the-river flows would then be handled by the spillways thus spoiling the generation of renewable energy.

- Run-of-the-river (as well as thermal power plants) cannot handle negative residual load (residual load = demand – renewables (PV, wind, hydro) – must run power plants (like nuclear and lignite)). Pumped storage hydro can handle such negative residual load since it is equipped with pumps. The power of pumped storage hydro is fully dispatchable in a positive and negative direction.

- Pumped storage hydro can provide grid scale load changes in both generating and pumping modes in case of variable speed technology. Pumped storage hydro provides significant ancillary services (since it is equipped with a significant storage capability) such as:
  - spinning reserve (primary control) in generating and pumping mode,
  - fast balancing reserves for secondary and tertiary grid frequency control,

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- fast compensation of forecast errors created by wind and solar,
- congestion management of high-voltage transmission lines (re-dispatch),
- voltage control in synchronous condenser mode,
- grid stability, such as islanding operation and black start capability.

Question 4: You mention in your written statement that pumped hydro storage is "underutilized." Can you explain this further? If it were more fully utilized, to what extent would pumped storage displace other energy storage technologies on the grid?

Answer: Energy storage is clearly needed across all types of grids throughout the United States. Pumped storage hydro is the only proven, large-scale form of storage and accounts for 97% of grid storage capacity, but it's not the only storage option. In fact, it shouldn't be the only option since its unique topographical requirements limit where pumped storage hydro facilities can be built. We don't view expanded pumped storage hydro as displacing other storage technologies, but rather supplementing and working in concert with them. As is the case with our energy supply, we need to responsibly utilize all available technologies and sources to meet future demand.

Today, pumped storage hydro is significantly underutilized. The Department of Energy's Hydropower Vision Report identifies many of these opportunities, and determined that pumped storage hydro can grow by 36 gigawatts – more than doubling current installed capacity. That statistic alone illustrates the extent to which pumped storage is underutilized.

Question 5: Dams and hydro facilities have an impact on the environment – as do batteries and other technologies. Are you aware of any analysis comparing the environmental impacts of these technologies?

Answer: We are aware of comparisons currently being studied in academia and industry. Some of the themes that are becoming evident include:

- batteries have a limited life time due to chemical process – with a maximum of 15 to 20 years, whereas pumped storage hydro is 100 years
- the load cycle of a battery is limited – 3000 to 5000 load cycles compared to pumped storage hydro at 50,000 to 950,000 load cycles
- the chemical recycling and disposal of used/damaged batteries is not yet finalized
- life cycle greenhouse gas emissions for a typically sized pumped storage facility of more than 1 GW capacity and more than 8 hours load cycle are substantially lower than the erection and operation of a comparably sized battery storage facility

Question from Senator Ron Wyden

Question: In your testimony, you described innovations in the technology behind pumped hydro storage that allow systems to respond to grid more quickly. I recently introduced a bill, S.1875, that would increase the flexibility, efficiency, and reliability of the grid.

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Do you believe that, given sufficient R&D investment, further innovations in pumped hydro storage are possible that would increase its value to the grid of the future?

Answer: Yes, absolutely. While pumped storage hydro follows the same basic principles that it did when it was introduced over a century ago, the technology has advanced significantly. Not only is pumped storage hydro more efficient, but it is also able to respond to grid demands within milliseconds. This reduces power outages and ensures a steady flow of power to customers, while also allowing for a more streamlined integration of renewable sources into the grid.

In my written testimony, I applauded the work of Senator Cantwell to include new investment in grid storage R&D in the Energy and Natural Resources Act of 2017. That's a great first step, because I do believe the federal government, through the Department of Energy and FERC, can play a positive role in researching and ultimately developing new energy storage technology. We encourage researchers to work with private industry on their efforts to ensure these technologies can be deployed.

We also applaud you and your colleagues' work on grid reliability and storage in general, as represented by S. 1875. How we utilize these technologies will only grow in importance over the coming decades and the committee deserves credit for proactively examining these issues.

David S. Abraham
Senior Fellow
New America

The world is on the precipice of an amazing advancement: the ability to produce and store vast amounts of energy. We will soon look back at today's smartphone battery as we do the calculator and see it as useful, but extremely limited.

As the size, power and capacity of energy storage technologies increase from powering phones to running cities, we must understand that there are resource implications to this transition.

As we increase our reliance on batteries, especially for vehicles, this revolution will free the average American from the gas pump, uncoupling them from the resource dependencies of the last generations. But this transformation will not free us from our reliance on resources. Instead, we are trading one resource dependence for another with entirely new economic, geopolitical, environmental and security implications that must be understand.

Battery materials made from elements including cobalt, lithium, nickel, graphite, rare earth elements and vanadium are at the forefront of this new revolution in energy. Some are concerned we are running out of these resources. After all, many of these battery materials were just scientific curiosities a generation ago. Now they are entering mass use.

The U.S. Department of Energy and the European Union both fear that the resources needed to produce many of the next generations' products may face shortages. The American Chemical Society reported earlier this decade that half the elements are at risk of resource shortage over the coming century.

I do not believe that we now face a geologic resource shortages for any mineral. However, I am concerned that we will face resource shortfalls over the next decade that will otherwise limit the adoption of battery technologies due to non-geologic reasons: spikes in demand, the slow development of supply chains of battery-grade materials and the resource policies of other countries.

Understanding the Resource Dynamic

To meet our energy storage ambitions, it is critical to examine the flow of these resources, understand where they are produced and how they get to the companies that need them. Indeed, some of the companies who rely on these batteries often have little idea the long-term risks of battery-material supply lines. The challenge for them and our economy is to ensure that our supply lines will produce enough of the right material, in the right grade that gets to the right supplier at the right time and cost (both environmental and economic).

Today's battery-powered gadgets are spreading around the world far faster than any other manufactured product in history. Within four years of the smartphone's launch, nearly six percent of the world's population had one. No product, not the air-conditioner, telephone or radio, spread around the world more quickly. A few years later the tablet computer accomplished the same feat with greater speed. Our newer products will face even faster demand dynamics in an increasingly wealthy world. We must ensure that the rapid development in new technology demand does not outpace our ability to produce the material needed for them.

Potential shortfalls -- and fears of them from increased demand and uncertain supply -- will lead some companies to choose inefficient battery technologies. This is not some abstract theory. Just over five years ago, wind power companies such as General Electric shied away from designs that used rare earth elements. At that time, the price of rare earths spiked after Beijing cut off exports to Japan and employed greater export restrictions. In a globalized world, U.S. companies must have access to the resources they need.

Today, large multinationals are beginning to act to ensure battery resources. Volkswagen announced this month a contract for purchasing cobalt. While it does not use cobalt directly in its products, the company needs roughly 8-12 kg of cobalt material in each of the batteries in installs as it hopes to produce to millions of electric vehicles yearly.

The Challenges of Production

Often mining and material processing companies cannot just turn on the spigot to increase the number of battery materials to meet a spike in demand as is done for oil. Like fine scotch whiskey, production of new supplies takes time, in many cases, years.

Ensuring a timely, stable, and sufficient flow of materials faces many hurdles:

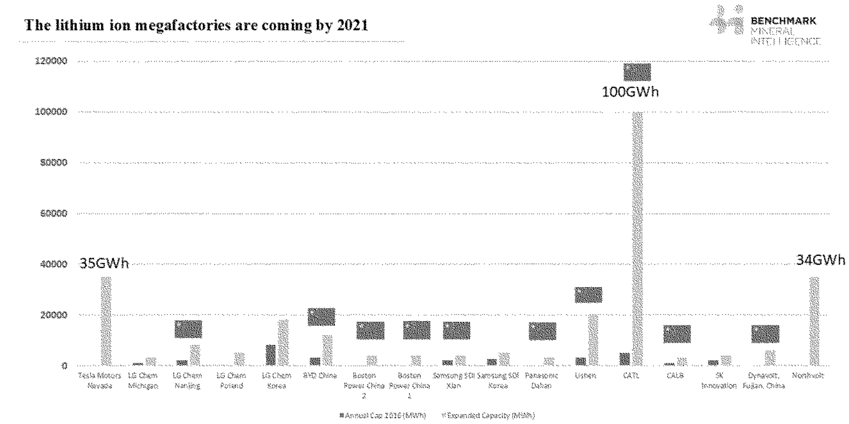
1) Developing a new mine takes a huge capital investment in markets that are slow moving and inefficient at allocating capital quickly. Mines can take several years to fund and up to 10 to 15 years to open.
2) Many of the battery materials are byproducts so they are not mined directly and are dependent on the production of a base material whose demand is not often linked to its byproduct.
3) Producing battery materials from minerals is a balancing act of acids and heat that can take many years to develop. There is often no "cookbook" to produce some of these materials.
4) Most of these materials are traded off exchanges in backroom deals, making it difficult to ascertain the size of the market, complicating investment decisions.
5) Regulations to establish a mine often take years to meet, meaning promising developments cannot be brought on quickly.
6) Often one country or one mine dominates the production of many critical battery materials leading to concentration risk.

Battery Material Demand

Each battery technology relies on very specific amounts of materials, with chemistries refined uniquely for a product's end use. But there are some general trends, led by the lithium ion batteries that are most in demand.

The research from Benchmark Mineral Intelligence is instructive. Last year the world needed 80 GWh of batteries to meet vehicle demands. By 2025, the demand is expected to be nearly ten times that at 650 GWh. For some perspective, 650 GWh produces 12 million Tesla Model 3-sized cars, 8.1 million sedan-style cars or 1.6 million e-buses or trucks.

The race to produce batteries is on. While the western media heralded the announcement of the Tesla Gigafactory, which will have the capacity to produce 35 GWh of batteries by 2020, a Chinese competitor, CATL has a far loftier goal: it is building a facility nearly three times larger, with a capacity of 100 GWh.



To supply the market, the amount of lithium battery material produced must increase from 80,000 tonnes to 600,000 tonnes, an increase of 650 percent. The demand would continue to grow by 10 to 20 percent per year post-2025. Cobalt demand will likewise would spike. According to Benchmark, the cobalt market would grow from 48,000 tonnes produced annually to 100,000 tonnes of battery-grade cobalt material. (The total amount of cobalt produced in last year was 96,000 tonnes). Nickel would also face similar spikes. It should be highlighted that the resource risk does not stem solely from the total amount of resources in the ground but also the capacity of processing lines to turn minerals into materials.

Geopolitical Risk

We also must be cognizant of where these resources are mined and produced. The countries in parenthesis is where most the material is mined or produced: lithium (Australia, Chile, China), cobalt (DRC, China), manganese (South Africa, China, Australia), vanadium (China), and rare earths (China).

Cobalt is of particular concern. More than half is produced in the Democratic Republic of the Congo, which is historically unstable and corrupt. What's more, approximately one-fifth comes from artisanal mining, raising environmental and human rights concerns as well. After the mining, much of the world's cobalt is processed in China where the risk continues.

Indeed, most of the battery materials, especially critical ones, are almost exclusively mined in China, like rare earths, or processed there, as in cobalt. Therefore, the chokepoint for future resource could well be in Asia.

As China embarks on its new industrial policy, Made in China 2025, the country is well on its way to dominating the mining, production and deployment of the entire global battery supply line. Beijing is using battery technologies and the materials that go into them to dominate the production of green energy technologies and the next generation of transport. It will see less reason to export battery materials freely to ensure supplies for these domestic industries.

The Role of Government

To ensure we can continue to develop resources, the U.S. must develop a new generation of mineralogists and material scientists who can focus on battery technologies. Too many potential students have been guided to other careers, leaving few to replace the large numbers leaving the fields. Funding to support our research universities is critical.

The government must also encourage the development of standards to lead to more efficient use of resources, and regulations when needed to encourage greater recycling and reuse of materials with a focus on supporting a circular economy. The market does not always lead to efficient post-use material disposal, as, for example, recycling batteries is not often profitable. At the same time, permitting for mining should be re-examined as development policies must maintain clear, stringent environmental standards, but allow for faster development of resource areas.

We also must consider restoring offices in the Department of State that look at mineral resources and fund the United States Geological Survey to reinvigorate a resource department that has been hurt through attrition and funding cuts over the decades.

The International Materials Agency

Internationally, U.S. trade policy has worked to encourage the free flow of resources. Such work is vital but insufficient for battery materials. To produce more informed market data and reduce the specter of conflict over resources that will increase over the next generation as the world relies on more mined resources, it is critical to develop an international forum to discuss mined resources.

I propose the International Materials Agency in the mold of the International Energy Agency, which researches oil and energy markets and promotes diversity, efficiency and flexibility within all energy sectors. The Agency would also introduce transparency to markets that are often lacking in it.

The International Materials Agency would address potential resource concerns, collect statistics, draft market analyses, and create a forum for dialogue in an attempt stem resource conflict. Currently, resource conflicts are ineffectively addressed at the World Trade Organization.

A century ago we adopted the use of oil and gas as the mainstay of our economy without considering or appreciating the impact. We are now well placed to understand the new energy dynamic behind energy storage and make sure we have the resources needed to support it.

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Subject: Full Committee Hearing to Examine Energy Storage Technologies

I fully enjoyed today's Full Committee Hearing to Examine Energy Storage Technologies and listening to the discussion around batteries and pumped hydro however there was a huge piece of the puzzle missing -- **Thermal Energy Storage (TES).**

As the New York Times pointed out on June 3rd, **TES is a different type of battery.** TES is as common as hot water heaters and as innovative as **ice storage cooling** tanks found in high profile buildings around NYC as well as in high schools, hospitals, retail, government facilities and many other applications. Currently, there are over 4,500 installations and 1,000 MW of ice based TES in 60 countries. Our organization manufactures ice thermal energy storage tanks in New Jersey, **supporting local job creation.**

What makes TES a **smart investment for American business** is that it cost a **tenth of what batteries cost** and replaces peaking plants at a fraction of the price. Plus, ice TES is proven to work and the raw materials are 99% reusable or recyclable.

In addition, TES addresses the economic and societal problems associated with air-conditioning on the grid. **Why is this important?** Air-conditioning alone makes up to 40% of the grid's yearly peak demand. This air-conditioning demand drives up the price of grid electricity and is **the main reason utilities need to have more peaking plants.** These peaking plants are many times sited in the most disadvantaged neighborhoods.

Cleaner, more reliable, flexible energy storage resources can replace these peaking plants and TES is best suited to do so since **TES stores cooling -- the main culprit behind the need for peaking plants.** Batteries address electrical loads for lights, however, it would be highly inefficient and costly to store energy in a battery only to have it transformed yet again to create instantaneous cooling. Instead, distributed scale **TES and batteries** must be implemented together **to provide capacity and pair with renewables.**

A peak demand set by the 2008 heatwave in CA led to more power plants being built in case of an emergency. This has led to California ratepayers footing a bill almost $7 billion higher than they had in 2008 according to the LA Times. "Although California uses 2.6% less electricity annually from the power grid now [in 2017] than in 2008, residential and business customers together pay $6.8 billion more for power than they did then." If new power plant construction and new transmission lines are avoided and retired plants are replaced with energy storage, electricity costs can be reduced. And utilities facing lower energy consumption can be fairly compensated by charging based on customer peak demand.

In conclusion, I invite you to consider more seriously the role of **TES for the American Grid.** Consider, for example, tax deductions for businesses that install TES. Our organization has 120 years of energy storage experience to share and would be honored to be heard at a future hearing. In the meanwhile, keep an eye out for an upcoming PBS Ask This Old House Segment which will showcase our ice based TES system tied to solar at a home in North Carolina and see the promise of ice thermal energy storage for American homes for yourself.

Sincerely,

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Senate Committee on Energy and Natural Resources
Date of hearing: October 3, 2017
Subject: to Examine Energy Storage Technologies

The efforts by this Committee to examine and assess the viability of energy storage technologies and to forecast the innovation of tomorrow's technologies are the right steps forward in ensuring energy security for future generations as well as providing new methods to adequately respond to natural disasters.

Need for Legislation

As a nation we have endured the negative impacts of large-scale emission based energy production; impacts that we now know far outweigh the inexpensive prices today on electricity generation and supply. We must turn to renewable outlets to subsidize our need for energy security, to further ensure economic prosperity while balancing our responsibilities as stewards of the environment. The issue that arises within these renewable technologies is the environment society relationship itself. The sun can loose intensity based on cloud coverage, the wind changes direction throughout the day and American society requires a reliable supply of energy to function. If we are to travel this path of energy source transition, we must also develop the capacity to store and ultimately distribute the energy produced, while keeping what energy is leftover. This can be achieved by further conversations on the subject of energy storage and the proposals of legislation that will assist in the development of these technologies as we move towards a cleaner national energy grid. Assembly Bill 2514 enacted in the legislature of California provides an excellent blueprint for how we should approach national energy storage policies. By incentivizing large utility companies to invest in storage technology we will be able to "streamline the time and costs associated with interconnecting new energy resources"[2]. Legislation along a similar vein would reinforce the commitments to national grid restructuring that requires adaptation to the new forms of electricity production and distribution.

Issues of Market Dominance

The technological advancement within the United States, in terms of energy storage is vastly diverse yet, untested. These include: Pump Hydro (PH), Flow Batteries, Fuel Cells, Hydrogen, Thermal, Phase-Change materials, among others currently in development. Each of these show promise while containing various issues including: possibilities of market domination, geography, access to materials, negative cost-benefit relationship and technological shortcomings. PH, for example, accounts for a large percentage of back-up and storage capacities currently in use; they are however hindered within some geographic areas that lack adequate elevation differentiations as well as the likely requirement of damming[1]. Between 2010 and 2014 the storage capacity has nearly doubled from 160 MW to 350 MW which is attributed to the nearly 91% market share of PH[2]. It is within our best interest to ensure the diversification of grid energy storage technologies to avoid the inequities that may arise in this rapidly changing market, as well as possible geographical limitations. Assembly Bill 2514, does well to avoid the dominance of a singular type of storage by limiting MW capacity[3]. *Reforming the Energy Vison*

[1] Táczi, I., & Szorenyi, G. (2016). Pumped Storage Hydroelectric Power Plants: Issues and Applications. *Energy Regulators Regional Association (ERRA): Budapest, Hungary.*

[2] Cara Marcy, U.S. Energy Information Administration (EIA), "Nonhydro Electricity Storage Increasing as New Policies Are Implemented," Today in Energy, April 3, 2015, http://www.eia.gov/todayinenergy/detail.cfm?id=20652

[3] California Public Utilities Commission. Order Instituting Rulemaking Pursuant to Assembly Bill 2514 to Consider the Adoption of Procurement Targets for Viable and Cost-Effective Energy Storage Systems, 2013. Southern California Edison.

a energy strategy for New York addresses this as well, calling for a far more competitive market in the energy sector as well as the distributive technologies[4]. Non-Hydro energy storage technologies will require additional support through legislative action which in turn will make enhance the market price trends projected. According to the Gird-Connected Energy Storage Report from Energy Storage Intelligence Service, between 2012 and 2015 the average price of lithium ion batteries fell 53 percent and are projected to fall even further within the decade[5].

Humanitarian Aid:

As we approach the new reality of increased storm intensity across the globe with warming surface water temperatures we will need to be more prepared than ever to address natural disaster recovery efforts. According to studies in recent years the rates of catastrophic level storms have been increasing along with a growing concentrated populations near disaster prone locations, leaving hundreds of millions in the wake of these disasters[6]. Further emphasizing the need for more efficient disaster relief efforts. Recent natural disasters like hurricane Maria crippled entire energy grids, tearing down power lines leaving the 3.4 million residents of Puerto Rico without power. This lack of a functioning gird crippled all energy dependent infrastructure. The ability for assessments to damage, policing efforts, communication

[4] New York State Public Service Commission. (2014). *Reforming the energy vision.* Staff Report and Proposal. Case 14-M-0101.

[5] Wilkinson, Sam. Price Declines Expected to Broaden the Energy Storage Market, IHS Says. (IHS, November 23, 2015)

[6] Jennifer Leaning, and Debarati Guha-Sapir, "Natural Disasters, Armed Conflict, and Public Health," National England Journal of Medicine, November 2013.

capabilities, and economic institutions to function, all coalesce to form an even larger problem related to their ability to access abundant and reliable sources of electricity.

Hospitals first and foremost would benefit from a resilient type of energy grid in post-disaster response. Currently we are seeing Puerto Rican hospitals rely on generators in effort to continue to care for pre-disaster patients and accommodate new patients post-disaster. This reliance on a finite resource does little more than impose an even greater burden on these facilities along with the already daunting task of caring for those affected on limited supplies. The introduction of portable battery systems would be able to supply a backup energy source in these type of events, easing the recovery process.

If the United States is to continue being a purveyor of humanitarian assistance, on a national and international scale, we must look to integrate newer resilient energy storage technologies to ease the process of recovery and avoid the exacerbation of the crisis. This Congress should look to appropriate greater funds to disaster relief specifically concerning the deployment of energy storage technologies along with further funding to research ways to diversify these mediums of portable storage to enhance our domestic energy security. Within the framework of systems thinking, it is highly unlikely that any singular entity will provide the answer or act upon that answer "without strong regulatory structure companies will not risk capital investment and require payback of many years, however good the technology"[7].

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[7] Confino, Jo. (2012, October 15). The Art of System Thinking in Driving Sustainable Transformation. Retrieved from https://www.theguardian.com/sustainable-business/systems-thinking-sustainable-transformation.