

U.S. DEPARTMENT OF ENERGY
OFFICE OF ELECTRICITY ENERGY STORAGE PROGRAM
at SANDIA NATIONAL LABORATORIES

FY21
SUMMARY

Accomplishments & Impacts



Sandia
National
Laboratories

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Notable Accomplishments

During this fiscal year, Sandia contributed to multiple energy storage system installations, received prestigious professional and technical recognition, and organized multiple technical symposia. Brief descriptions of these and other selected accomplishments are provided on pages 2 through 15.

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Publications

Sandia researchers produced a large number of energy storage-related publications, including 60 peer-reviewed journal papers. A list of publications is provided on pages 16 through 23.

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Patents

Sandia's efforts have produced a number of patents and applications on topics that include Systems and Methods for Controlling Electrical Grid Resources, Solar-Battery Integrated DC System, Sodium Electrochemical Interfaces with NaSICON-Type Ceramics, and many more. One patent granted and seven additional patent applications have been filed and are listed on pages 27 through 29.

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Technical Conferences and Presentations

Sandia researchers were invited to talk at multiple conferences, contributed to numerous technical presentations, participated in organizational workshops and symposia, and webinars. These technical conference contributions and additional presentations are listed on pages 30 through 38.



INTRODUCTION

Energy storage is beginning to play a growing role in improving the reliability and resiliency of the electric grid. Currently, grid energy storage systems are being deployed for a wide range of applications. Further improvements in cost and performance metrics are needed to make energy storage cost effective across all application markets in the electricity infrastructure. The Grid Energy Storage Program at Sandia National Laboratories is focused on making energy storage cost effective through research and development (R&D) in new battery technologies, advancements in power electronics and power conversion systems, improving the safety and reliability of energy storage systems, development of analytical tools for valuation of energy storage, and validation of new energy storage technologies through demonstration projects. During the 2021 fiscal year, Sandia executed R&D work supported by the U.S. Department of Energy's (DOE) Office of Electricity – Energy Storage Program under the leadership of Dr. Imre Gyuk. This document summarizes the impact of Sandia's contributions through notable accomplishments, journal publications, patents, and technical conferences and presentations.

Dr. Babu Chalamala
Program Manager, Energy Storage

The background of the slide features a blurred image of a target with several arrows hitting the bullseye. A solid blue horizontal band is overlaid across the middle of the image, containing the text.

Notable Accomplishments

NOTABLE ACCOMPLISHMENTS

BATTERY MATERIALS RESEARCH

Erik Spoerke and Clifford Ho from Sandia National Laboratories, supported by PNNL and ORNL, hosted the DOE workshop: [“BIG” Energy Storage: Priorities and Pathways to Long-Duration Energy Storage](#). The highly successful workshop on March 9-10, 2021 was well-received and had more than 1500 registrants (500-600 simultaneous participants each day) and included national and international participation across industry, multiple national laboratories, academia, and government. This OE-led activity had active engagement across OE, EERE, ARPA-E, HFTO, VTO, and more broadly the ESGC.

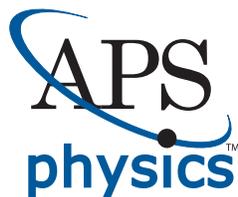
In collaboration with Urban Electric Power, the Energy Storage Materials team demonstrated a new high voltage (> 2.5V) dual electrolyte battery concept. Unlike previous “2V” Zn-MnO₂, specific design elements offer reduced cell volume while preventing electrolyte neutralization, important for higher energy densities and cycle life. A prototype battery has cycled over 36 times now with coulombic efficiency at 100% and energy efficiency >79-80%.

Tim Lambert and the ES Materials team demonstrated a self-assembled polymer coating approach capable of selective ion transport, solving one of the fundamental problems in alkaline Zn batteries, that of zincate crossover. Using commercially relevant energy-dense electrodes with high areal capacities of 60 mAh cm⁻², Zn-Ni cells tested at 20% Zinc depth of discharge (DOD_{Zn}) achieve over 200 cycles while those tested at 50% DOD_{Zn} achieve over 100 cycles before failure. The 20% and 50% DOD cells deliver an average of 132 and 180 Wh L⁻¹ per cycle over their lifetime respectively. Rechargeability is attributed to the highly selective diffusion properties of the 300 nm thick negatively charged coating on the separator which prevents shorting by dendrites and inhibits redistribution of the active material.

Ion-selective membrane development at Sandia, led by Cy Fujimoto, continued its industrial impact with Xergy Inc., renewing their license of seven of Fujimoto's OE-supported membrane patents. Xergy Inc. is a Delaware-based company with a commitment to engineering solutions with ion-exchange membranes.



The Energy Storage Sodium Battery Materials team developed new NaSICON synthetic strategy that produces 2X improvement in ionic conductivity and 4X improvement in synthetic yield. This material is now competitive with state-of-the-art industrial (former Ceramtec) NaSICON. This development will not only allow improved performance of low temperature molten Na batteries but is also being explored as a zero-crossover candidate for Zn-MnO₂ batteries and may be suitable for flow battery systems.



Amalie Frischknecht served as the Chair of the [Division of Polymer Physics \(DPOLY\)](#) of the [American Physical Society](#) from March 2020 through March 2021. She is continuing to serve on the DPOLY Executive Committee as the Past Chair until March 2022.

POWER ELECTRONICS



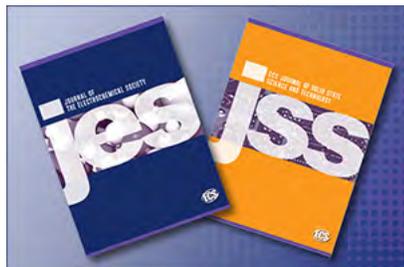
Luciano A. Garcia Rodriguez, Lee Gill, Jacob Mueller, and Jason Neely received the **Best Paper Award** for the paper “A High-Voltage Cascaded Solid-State DC Circuit Breaker Using Normally-On SiC JFETs” presented at the [IEEE 12th Energy Conversion Congress & Exposition – Asia \(IEEE ECCE – Asia\)](#), May 24-27, 2021.

Jacob Mueller received the IEEE Albuquerque Section **Outstanding Young Engineer award** for technical contributions to the field of power electronics. The award specifically highlighted his work developing computationally efficient models of multi-converter systems and high-performance power conversion strategies for utility-scale energy storage. Read more at <https://site.ieee.org/albuquerque/>.



The Power Electronics team, under the leadership of Stan Atcitty, worked with InnoCit, LLC, to build a 100 kW GaN inverter system which achieved an overall efficiency of 98.5%, and GeneSiC Semiconductor to demonstrate a 3300 V/50 mOhm monolithic SiC switch-based power conversion system.

SAFETY & RELIABILITY



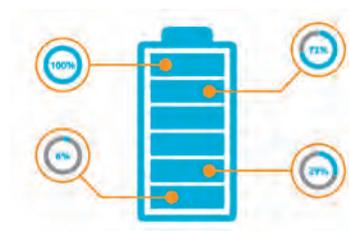
For one full year, “[Degradation of Commercial Lithium-ion Cells as a Function of Chemistry and Cycling Conditions](#)” by Yuliya Preger, Heather Barkholtz, Armando Fresquez, Daniel Campbell, Benjamin Juba, Jessica Roman-Kustas, Summer Ferreira, and Babu Chalamala, was cited as one of the five most downloaded papers in the Journal of the Electrochemical Society. In the year since publication, it has been downloaded over 23,000 times.

Sandia organized the [Energy Storage Systems Safety & Reliability Forum](#) (April 20-21) on behalf of the Office of Electricity Grid Energy Storage Program. Conference organization was led by Josh Lamb (7546) with support from David Sokoloff, Marisa Montes, and Sam Roberts. At its peak, there were over 300 attendees in the virtual meeting. The event included participants from national laboratories, independent testing and research organizations, battery manufacturers, electric utilities and first responders.



Josh Lamb, lead for the Energy Storage Safety & Reliability program, was Guest Editor for the May 2021 of the MRS Bulletin Special Edition on Materials Developments in Battery Safety.

In September 2020, Valerio De Angelis and Yuliya Preger launched [BatteryArchive.org](#), the first public repository for easy visualization and comparison of battery degradation data across institutions. In the year since launch, the site has been used by thousands of individuals across academia, industry, and utilities to understand how lithium-ion batteries perform in different conditions and to save money in their own testing.



Randy Shurtz and John Hewson released the thermodynamic web calculator at <https://www.sandia.gov/ess-ssl/thermodynamic-web-calculator/> allowing users an easy tool for estimating the heat production during battery failure based on user entered parameters. This provides a tool to drive toward the model-based design of grid-scale battery systems.



John Hewson was selected co-chair of the Research Subcommittee for the International Association of Fire Safety Science (IAFSS). The Research Subcommittee mission is to highlight research needs in emerging areas and research results from the IAFSS member community that can be applied to these emerging areas. Energy storage safety is one of the emerging areas of focus.

Valerio De Angelis and Yuliya Preger open-sourced the [Battery Lifecycle \(BLC\) Framework](#) software. The BLC is an open-source platform that provides tools to visualize, analyze, and share battery data through the technology development cycle, including data from material characterization, cell testing, manufacturing, and field testing.



V. O'Brien, R.D. Trevizan, V.S. Rao "Detection of False Data Injection Attacks Targeting State of Charge Estimation of Battery Energy Storage Systems" won **First Place in the poster competition for graduate students** at the [11th Advanced Energy Conference \(AEC\)](#). Victoria O'Brien is currently performing her dissertation research at Sandia.

ANALYTICS



The goal of the energy storage analytics thrust area is to develop methods and algorithms to evaluate energy storage systems from both a technical and economic perspective. QuEST is the flagship open-source energy storage valuation tool that is available on [GitHub](#). This year we released a new version of QuEST that incorporates a technology selection tool. We also developed the back end of two new applications: QuEST Equity and QuEST Performance. QuEST Equity evaluates peaker plant replacement with storage plus solar while considering energy justice considerations (e.g., negative impacts of pollution from peaker plants in urban areas). QuEST Performance employs a building and HVAC model to properly size energy storage systems in extreme (hot and cold) climates. Often the parasitic loads from heating and cooling impact the required storage system size and these factors are often not considered.

In collaboration with Richard Baxter at Mustang Prairie Energy and K&L Gates, Sandia organized two energy storage finance summits. These meetings bring together leaders from finance with energy storage developers and government officials. In addition, Sandia worked with Richard Baxter to update the annual energy storage pricing survey.



Energy, Minerals and Natural Resources Department

The Energy Storage Analytics team continued to perform analysis efforts for demonstration projects including Picuris Pueblo (New Mexico), Rhode Island, Isle Au Haut (Maine), North Carolina Electric Cooperatives, Hyde Park (New Mexico), Vermont Electric Coop, and Poudre Valley (Colorado).



Signed a cooperative research and development agreement (CRADA) with PNM to develop tools to assist utilities size, locate, and value energy storage as they work toward decarbonization goals and mandates. Initial efforts have quantified the variability of proposed renewable generation and the ramp rate requirements to maintain reliability. This variability will be used to estimate the quantity of energy storage required for ancillary services (e.g., frequency regulation, spinning reserve, etc.). In addition, the project team has started analyzing scenarios using an in-house production cost modelling tool (EGRET/PRESCIENT).

- In February 2021, the IEEE-SA Standards Board approved the formation of the Working Group, “Energy Storage Management Systems in Grid Applications,” whose purpose is to draft a standard for recommended practice in the development and deployment of Energy Storage Management Systems (ESMS) in grid applications. David Schoenwald is the Working Group Chair, and Tu Nguyen is the Working Group Vice-Chair. This working group is currently active with regular monthly meetings. A draft of the recommended practice is expected to be ready for balloting by IEEE-SA in late 2022.



- Michael Ropp co-chaired the P1547.9 Working Group. IEEE P1547.9 “Draft Guide for Using IEEE Std 1547™ for Interconnection of Energy Storage Distributed Energy Resources with Electric Power Systems” is an all-new standard designed to streamline the interconnection of energy storage systems with distribution systems by clarifying and expanding on the application of IEEE Std 1547-2018 to energy storage. This standard was co-sponsored by Standards Coordinating Committee 21 and the Energy Storage and Stationary Batteries committee, thus bringing together power systems and energy storage SMEs in a way not previously done in the 1547 series of standards.
- David Rosewater served as chair of IEEE working group 2686 - Battery Management Systems in Energy Storage Applications. The working group has developed full descriptions of battery management functions including voltage management, current management, temperature management, and charge management and has made strides this year in formulating specific recommendations on appropriately configuring a BMS to a specific battery technology in a specific grid connected application. This work is actively building consensus and best practices for battery management design.

Other notable accomplishments include:

- Strengthened our collaboration with Quanta Technology to improve distribution expansion planning for energy storage. This includes the development of a probabilistic integrated resource planning tool that will be incorporated into QuEST in 2022.
- Filed a provisional patent application for “Energy Storage-based Packetized Delivery of Electricity” which also leverages a Laboratory Directed Research and Development project.



DEMONSTRATION PROJECTS



The Energy Storage Demonstration Projects team was selected to lead the Project Development and Deployment for the DOE Social Equity for Energy Storage program. Projects for this program will be selected in alignment with the DOE's Justice40 initiative which supports disadvantaged communities affected by unreliable and expensive energy system and supplies.

The Demonstration Projects team provided (in collaboration with PNNL) safety and operations best practices training to first responders and local fire departments. In FY21, training was provided to the **Decorah, IA Volunteer Fire Department** for the recently commissioned Alliant Energy project and to the **Red Feather Lakes & Crystal Lakes, CO Volunteer Fire Department** for the Poudre Valley/NRECA project.



The Energy Storage Demonstration Projects team entered into a Memorandum of Understanding (MOU) with the **California Energy Commission (CEC)**, establishing the framework for how Sandia and the CEC will coordinate to advance energy storage technologies in California. As part of this MOU, Sandia will assist CEC in a range of activities including technical evaluation of projects and performance validation of commissioned projects.

The Demonstration Projects team is active in many states throughout the country. Examples include:

- Providing technical assistance with RFP and bid analysis resulting in the July 2021 commissioning and ribbon cutting of the 2.5MW, 2.9MWh **Alliant Energy BESS installation in Decorah, IA**, which also includes a data sharing agreement in which Sandia is receiving live, streaming BESS data which will be used to validate many laboratory level tests and theories with real-world operational data.



- Providing technical assistance for sizing, economic analysis, and project development for the four partnership projects with **NRECA's Rural Energy Storage Deployment Program (RESDP)**. Of the four, one is complete, two are in the construction and equipment installation phase, and one is awaiting equipment delivery. Three are expected to be fully operational by late 2021 / early 2022.
- Providing technical assistance to the **Alaska Village Electrical Cooperative (AVEC)** project which will electrically connect two rural villages (St. Mary's & Mountain Village) together via a grid bridge system supported by a 1MW, 1MWh BESS.
- Provided technical assistance with the RFP, project development, and the project design review for the **Albuquerque Public Schools' Atrisco Heritage Academy High School** project. The project has completed the BESS system site design and has received the stamped and approved design drawings. The 721 kW Tesla Megapack 2 battery system has been procured and on-track for delivery June 2022.
- Providing technical assistance to **Santa Fe Community College** throughout their 100kW/85kWh battery energy storage system project which is successfully commissioned and ready for microgrid operations. The Sandia Demonstrations Projects Team is also coordinating with the college and local first responders to provide first responder safety training.
- The first of three UEP Zinc-Manganese Oxide 3kW/13kWh battery systems for the **Navajo Tribal Utility Authority project** have been delivered to the Demonstration Projects team for pre-deployment assembly and testing. The UEP system utilizes a new zinc technology that will be assessed to determine whether it is a viable replacement for the high maintenance flooded lead acid batteries currently in use in NTUA's fleet of off-grid residential solar PV/ battery systems. The system is expected to be deployed in Q1 of FY22.



POLICY & OUTREACH

The Energy Storage Policy & Outreach team, led by Will McNamara and Howard Passell, provided a direct service to state commissions by hosting independent, objective, educational webinars for state regulators about energy storage issues to better equip them to make sound energy storage policy decisions and achieve clean energy goals.

The team met this objective primarily through the delivery of customized workshops to state public utility commissions (PUCs) including presentations on energy storage technology, economics, and policy topics specific to the state's interests. These workshops featured subject matter experts from both within SNL and other national laboratories, and representatives from industry, universities, or other regulatory bodies.

See the Webinars section for details of all their PUC webinars held in FY2021.



OTHER ACHIEVEMENTS & RECOGNITIONS



Urban Electric Power was selected as one of the two winners of the [IEEE Division New Electrochemical Technology \(NET\) Award](#). UEP and the City University of New York Energy Institute, in collaboration with Sandia National Laboratories with research funding from the DOE Office of Electricity, have achieved several breakthroughs in addressing challenges of irreversible degradation by utilizing chemical dopants and additives to stabilize both the Zn anodes and MnO₂ cathodes, which allow for more complete utilization of the battery capacity while maintaining hundreds to thousands of cycles. The NET Award was endowed by the Dow Chemical Company Foundation to recognize significant advances in Industrial Electrochemistry.

Dr. Kaushik Rajashekara, a Distinguished Professor of Electrical Engineering at the University of Houston, was selected to receive the [2021 IEEE Medal for Environmental and Safety Technologies](#) for contributions to the advancement of transportation electrification technologies for the reduction of emissions and for improving energy efficiency. Dr. Rajashekara is a research collaborator with Sandia in the OE Energy Storage Program in the area of power electronics. His group has generated innovative solutions for connecting battery energy storage directly into medium voltage systems. These solutions improve the safety and reliability of large-scale battery storage systems by leveraging state-of-the-art devices and advanced control methods.



Prof. Bruce Gnade was recognized with the [2021 IEEE J.J. Ebers Award](#), which is the highest recognition from the IEEE Electron Devices Society for contributions to the field of electron devices. He was recognized for materials contributions to CMOS and flexible electronics technologies. As a collaboration with the Sandia Energy Storage Power Electronics program, Dr. Gnade and his team at Southern Methodist University have been doing significant work in understanding capacitor reliability issue, with a focus on materials characteristics associated with high voltage breakdown.

Lisa Housel, a recent Ph.D. graduate in Chemistry at Stony Brook University, was awarded the [ECS Energy Technology Division Graduate Student Award sponsored by Bio-Logic](#) partly for her work funded by the DOE Office of Electricity and Office of Science. This award recognized her contributions to understand the impact of charge transport properties on the structural change and electrochemistry of different battery materials.



Members of the Sandia Energy Storage program have been selected to join the Connect with an Expert portion of the DOE Lab Partnering Service, which allows users to quickly get answers to technology innovation questions and provides opportunities for potential partnerships.

The Sandia Energy Storage program wrote, edited, managed, and published the following chapters for the DOE Energy Storage Handbook:

- Chapter 3: Lithium-ion Batteries – Y. Preger, L. Torres-Castro, J. McDowell
- Chapter 4: Sodium-Based Battery Technologies – E.D. Spoerke, M.M. Gross, L.J. Small, S.J. Percival
- Chapter 5: Rechargeable Zinc Batteries – M. Lim, T. Lambert
- Chapter 6: Redox Flow Batteries – L.J. Small, C. Fujimoto, T.M. Anderson, H. Pratt
- Chapter 11: Hydrogen Energy Storage – A. Headley, S. Schoenung
- Chapter 12: Thermal Energy Storage Technologies – C.K. Ho, A. Ambrosini
- Chapter 13: Power Conversion Systems – J. Mueller, S. Atcitty, M. Ropp
- Chapter 16: Energy Storage Performance Testing – D. Rosewater, D. Schoenwald
- Chapter 18: Physical Security and Cybersecurity of Energy Storage Systems – J. Johnson, R. Trevizan, J. Hoaglund, T. Nguyen
- Chapter 20: Procurement – D. Borneo, T. Olinsky-Paul, S. Schoenung
- Chapter 21: Commissioning – D. Borneo, B. Schenkman, S. Schoenung
- Chapter 23: Applications and Grid Services – T. Nguyen, R. Byrne, R. Trevizan, A. Bastos, F. Wilches-Bernal, et. al.
- Chapter 24: Energy Storage Policy & Analysis – W. McNamara
- Chapter 25: Energy Storage System Pricing – R. Baxter, R. Byrne





Publications

PUBLICATIONS

JOURNAL PUBLICATIONS

- O. Aldosari, L.A. Garcia Rodriguez, G.G. Oggier, J.C. Balda "A Three-Level Isolated AC-DC PFC Power Converter Topology with a Reduced Number of Switches" IEEE Journal of Emerging and Selected Topics in Power Electronics, Vol. 9, Issue 1, pp. 1052-1063, Feb. 2021, DOI: [10.1109/JESTPE.2019.2962704](https://doi.org/10.1109/JESTPE.2019.2962704).
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- D. Copp, T.A. Nguyen, R.H. Byrne, B.R. Chalamala "Optimal Sizing of Distributed Energy Resources for 100% Renewable Planning" Energy, 2021, 122436, ISSN 0360-5442, DOI: [10.1016/j.energy.2021.122436](https://doi.org/10.1016/j.energy.2021.122436).
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- P. Dechent, A. Epp, D. Jöst, Y. Preger, P.M. Attia, W. Li, D. Uwe Sauer "ENPOLITE: Comparing Lithium-Ion Cells across Energy, Power, Lifetime, and Temperature" ACS Energy Letters, 2021, 6, 6, 2351-2355, DOI: [10.1021/acsenergylett.1c00743](https://doi.org/10.1021/acsenergylett.1c00743).
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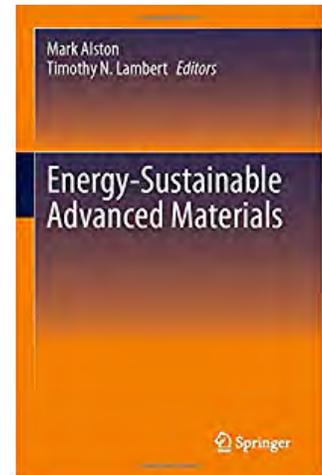
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Conference Proceedings



CONFERENCE PROCEEDINGS

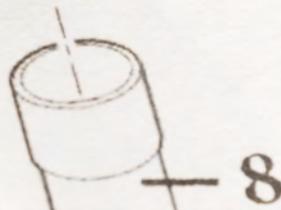
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- E.D. Spoerke “Molten Sodium Batteries for Seasonal Electrical Energy Storage” September 2020 (SD: 15586).

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Presentations

PRESENTATIONS

INVITED TALKS

- S. Atcitty “Role of Power Electronics and Wide Bandgap in Grid-tied Energy Storage Systems” South Dakota State University’s PES Day, April 13, 2021.
- S. Atcitty “Native American Energy Sovereignty: Energy Storage and Power Electronic Benefits” [Applied Power Electronics Conference \(APEC\) 2021](#), June 14-17, 2021.
- S. Atcitty “Role of Power Electronics and Wide Bandgap Semiconductors for Energy Storage Systems” and “Native American Energy Sovereignty: Energy Storage and Power Electronics Benefit” Missouri University Science & Technology Technical Seminar, Aug 31, 2021.
- B.R. Chalamala “Resilience Framework, Methods, and Metrics for the Electricity Sector” (Super session) [IEEE Power and Energy Society General Meeting](#), July 27, 2021.
- B.R. Chalamala “Safety of Grid Energy Storage Systems and Training Needs” (Panel on Energy Storage Grid Integration) [IEEE Power and Energy Society General Meeting](#), July 27, 2021.
- B.R. Chalamala “Energy Storage and Evolution of the Electric Grid: Stabilizing the RE Dominated Utility Grid Through Storage” (Keynote) [Intersolar India, Smarter E India Conference](#), December 10, 2020.
- B.R. Chalamala “Battery Energy Storage Technologies” (Closing Plenary) [ESIG 2020 Fall Technical Workshop](#), November 12, 2020.
- B.R. Chalamala “Energy Storage and Evolution of the Electrical Grid” University of Texas at Arlington, Electrical Engineering Colloquium, November 6, 2020.
- B.R. Chalamala “Advances in Grid Energy Storage: Implications for Operational Energy” [3rd DoD Power and Energy Summit](#), National Harbor, MD, July 14, 2021.
- B.R. Chalamala “Energy Storage and the Electric Grid” [AIChE 2nd Battery and Energy Storage Conference](#), October 22, 2020.
- B.R. Chalamala “Electric Grid Modernization – Overview” Summer School on Materials for Energy Storage and Conversion, Ankara, Turkey, September 10, 2021.
- B.R. Chalamala “Energy Storage, Electrification, and Modernization of Electricity Infrastructure” [mESC-School 2021, International Summer School on Materials for Energy Storage and Conversion](#), September 10, 2021.

- B.R. Chalamala, V. De Angelis, E.D. Spoerke, C. Ho “Materials Technology Gaps for Low-Cost Grid Storage” 5th International Symposium on Materials for Energy Storage and Conversion, September 15, 2021.
- B.R. Chalamala “Best Practices for Bulk Energy Storage Integration in Power System” (Plenary Panel Session) [2021 IEEE PES Innovative Smart Grid Technologies Latin America \(ISGT-LA\)](#), September 16, 2021.
- A.L. Frischknecht “Morphology and Ion Transport in Hydrated Ion-Containing Polymers” [American Chemical Society \(ACS\) Fall Meeting](#), Atlanta, GA, August 25, 2021.
- L.A. Garcia Rodriguez, L. Gill, J. Mueller, J. Neely “A High-Voltage Cascaded Solid-State DC Circuit Breaker Using Normally-ON SiC JFETs” [IEEE 12th Energy Conversion Congress & Exposition – Asia \(IEEE ECCE – Asia\)](#), May 24-27, 2021.
- J.C. Hewson “Modeling and Analysis of Battery Safety” [Energy Storage Systems Safety and Reliability Forum](#), April 20-21, 2021.
- J. Lamb “Development of DOE Energy Storage Safety Strategy Document” [Energy Storage Systems Safety and Reliability Forum](#), April 20-21, 2021.
- J. Lamb, et al. “Evaluating the impact of Energy Density on Thermal Runaway” [239th Meeting of Electrochemical Society \(ECS\)](#), May 30 – June 3, 2021.
- T.N. Lambert “Recent Progress in Alkaline Zn/MnO₂ Batteries” [NAATBatt International Workshop on Zinc Battery Technology III](#), the Advanced Science Research Center at CUNY, New York, New York, November 18, 2020.
- T.N. Lambert, N.B. Schorr, D.J. Arnot, et. al. “Advances in Alkaline Conversion Batteries for Grid Storage Applications” [2021 MRS Spring Meeting & Exhibit](#), April 17-23, 2021.
- T.N. Lambert “Alkaline Zn-based Batteries for Grid Storage Applications” Argonne National Laboratories Stationary Storage Speaker Series, June 17, 2021.
- W. McNamara and H. Passell “Energy Storage Policy and Outreach Program” and “Peace Engineering at Sandia National Laboratories” 11th Sandia Earth Science Symposium, May 24, 2021.
- T.A. Nguyen “Maximizing the Savings for Utility Customers using Behind-the-Meter Energy Storage” Sigma Xi - Science & Society Distinguished Public Talks, University of New Mexico, October 2020.
- T.A. Nguyen “Energy Storage Technologies and Grid Services” Current Status and Development Perspectives of Solar Photovoltaic Power Technology in Vietnam, June 2021.
- T.A. Nguyen “Energy Storage Management System and Valuation” IEEE Smart Grid R&D Committee Meeting, August 2021.
- T.A. Nguyen “QuEst – An Open-source Software Application Suite for Energy Storage Evaluation” DOE Energy Storage Financing Summit, September 2021.

- Y. Preger “A Survey of the Safety of Aged Li-ion Batteries” [Wards Intelligence, Focus: Electrification Conference](#), November 18-29, 2020.
- Y. Preger “Predictive Maintenance Practices for Operational Safety of Battery Energy Storage Systems” [International Battery Seminar](#), March 9-11, 2021.
- Y. Preger “Degradation of Commercial Li-ion Cells Beyond 80% Capacity” [Energy Storage Systems Safety and Reliability Forum](#), April 20-21, 2021.
- Y. Preger and J. Lamb “Battery Safety and Reliability: Tools to Understand Risk in Grid-scale Energy Storage Systems” at a Department of Energy (DOE) Lunch and Learn.
- Y. Preger and J. Mueller “Influence of Current Ripple on Battery Degradation” at the Battery Safety Council Forum 9, November 2020, and the Interagency Power Group Chemical Working Group Safety Panel, February 2021.
- M. Ropp “IEEE P1547.9: A New Standard to Help Streamline Energy Storage Interconnection with Distribution” [Energy Storage Systems Safety and Reliability Forum](#), April 20-21, 2021.
- D.M. Rosewater “Grid-scale Energy Storage Hazard Analysis & Design Objectives for System Safety” [Energy Storage Systems Safety and Reliability Forum](#), April 20-21, 2021.
- E.D. Spoerke “Hydrogen’s Contributions to a Clean, Long-Duration Energy Future” Western Green Hydrogen Initiative (WGHI) Virtual Summer Workshop, June 2021.
- E.D. Spoerke “Materials Chemistry in Energy Storage: A Key to Unlocking Our ‘Potential’ Energy Future” Fall Chemical & Materials Engineering Department Seminar, University of Kentucky, September 2021.
- U. Tamrakar “Smart Inverter Functions and Features for Power System State Estimation” live presentation and Q&A during the panel session entitled “Technological Advancements for Large Scale Adoption of Smart-Inverters” at the [IEEE PES 12th Conference on Innovative Smart Grid Technologies \(ISGT 2021\)](#), February 16-18, 2021.
- L. Torres-Castro “Safety Overview of Battery Energy Storage System Technologies” [Resilience Week 2020](#), October 19-23, 2020.
- L. Torres-Castro “Are Batteries Safe?” University of Puerto Rico-Rio Piedras Seminar Series, April 7, 2021.
- L. Torres-Castro “Mitigation of Failure Propagation: A Model-Based Experimental Design” [Energy Storage Systems Safety and Reliability Forum](#), April 20-21, 2021.
- R.D. Trevizan “Cybersecurity of Internet-of-Things-based Smart Energy Storage Systems” [IEEE Power and Energy Society \(PES\) General Meeting](#), July 26-29, 2021.

- D.E. Turney “Overview of Performance and Cost of Known Technology” [NAATBatt International Workshop on Zinc Battery Technology III](#), the Advanced Science Research Center at CUNY, New York, New York, November 18, 2020.
- R. Wittman “Overview of Aqueous Battery Safety and Reliability Concerns” [Energy Storage Systems Safety and Reliability Forum](#), April 20-21, 2021.
- R. Wittman, H.D. Pratt III, T.M. Anderson, Y. Preger “Gas Evolution from Mixed-Acid Vanadium Redox Flow Batteries” [239th Meeting of Electrochemical Society \(ECS\)](#), May 30 – June 3, 2021.

TECHNICAL PRESENTATIONS

- B. Ale Magar, N. Paudel, T.N. Lambert, I. Vasiliev "Ab Initio Study of the Influence of Structural Defects on the Electrochemical Properties of MnO₂ in Rechargeable Zn/MnO₂ Alkaline Batteries" [Four Corners Section Meeting of the American Physical Society](#), October 23-24, 2020.
- B. Ale Magar, N. Paudel, T.N. Lambert, I. Vasiliev "First Principles Studies of the Cycling Mechanism of MnO₂ Modified with Bi, Cu, and Mg in Rechargeable Zn/MnO₂ Batteries" [March Meeting of the American Physical Society](#), March 15-19, 2021.
- A.M. Bates "Thermal Modeling of Liquid Electrolyte in Solid-State Batteries" [Solid-State Battery Summit](#), August 3-4, 2021.
- J. Cho, J. Huang, G.G. Yadav, M. Nyce, M. Weiner, A. Upreti, R.J. Messinger, S. Banerjee "Electrochemical Evaluation of the Application of Hydrogel Electrolytes to Rechargeable Zn | MnO₂ Alkaline Batteries" [Electrochemical Society PRiME](#), October 4-9, 2020.
- V. De Angelis and Yuliya Preger "[BatteryArchive.org](#) – Insights From a Public Repository for Visualization, Analysis, and Comparison of Battery Data Across Institutions" [239th Meeting of Electrochemical Society \(ECS\)](#), Virtual, May 30 – June 3, 2021.
- A. Furlani Bastos, T.A. Nguyen, R.H. Byrne "Optimal Dispatch of Energy Storage Systems for Harmonic Mitigation and Power Factor Correction" [30th International Symposium on Industrial Electronics \(IEEE ISIE\)](#), June 20-23, 2021.
- M.M. Gross, A.S. Peretti, S.J. Percival, L.J. Small, M. Rodriguez, E.D. Spoeerke "Advancing Low-Temperature Molten Sodium Batteries by Interfacial Engineering of Ceramic Electrolytes" [Electrochemical Society PRiME](#), October 4-9, 2020.
- M.M. Gross, A.S. Peretti, S.J. Percival, L.J. Small, M. Rodriguez, E.D. Spoeerke "Engineering Ceramic Electrolyte Interfaces for Low-Temperature Molten Sodium Batteries" [Materials Research Society \(MRS\) Spring/Fall Meeting & Exhibit](#), November 27 – December 4, 2020.
- M.M. Gross, S.J. Percival, R.Y. Lee, A.S. Peretti, M. Rodriguez, E.D. Spoeerke, L.J. Small "High-Performance Low-Temperature Molten Sodium Batteries Enabled by Improved Charge Transfer Across Interfaces" [2021 MRS Spring Meeting & Exhibit](#), April 17-23, 2021.
- J. Hernandez, A. Etemadi, S.J. Roberts-Baca, V. Koushik Muthyapu "Developing a Logistic Regression Method for Valuation of Grid-Level Energy Storage Systems" [8th IEEE Conference on Technologies for Sustainability \(SusTech 2021\)](#), April 22-24, 2021.
- S. Kolhekar, S. Banerjee "Effect of KOH Concentration on Mn(III) Dissolution in Rechargeable γ - MnO₂ Cathodes" [Electrochemical Society PRiME](#), October 4-9, 2020.

- R. Hill, Y.T. Cheng, A.S. Peretti, E.D. Spoecke, L.J. Small “Mechanical Characterization of Montmorillonite Sodium Ion Conductors” [Materials Research Society \(MRS\) Spring/Fall Meeting & Exhibit](#), November 27 – December 4, 2020.
- S. Kolhekar, S. Banerjee “Effect of KOH Concentration on Mn(III) Dissolution in Rechargeable γ -MnO₂ Cathodes” [Electrochemical Society PRiME](#), October 4-9, 2020.
- S. Kolluri, A. Subramaniam, P. Mittal, Y. Preger, K. Shah, V.R. Subramanian “Parameter Estimation of Lithium-ion Battery Models Using a Novel Tanks-in-Series Approach” [Electrochemical Society PRiME](#), October 4-9, 2020.
- W. McNamara “Energy Storage: An Overview of Emerging Policies at the State Level” [IEEE PES Energy Storage and Stationary Battery Committee, IEEE PES Industry Technical Support Leadership Committee](#), September 30, 2020.
- W. McNamara “Role of Energy Storage in Integrated Resource Planning” [Center for Advanced Power Engineering Research \(CAPER\) Fall Meeting](#), November 11, 2020.
- M.L. Meyerson and L.J. Small “Mediated Lithium-Sulfur Flow Batteries for Grid-Scale Energy Storage” [American Chemical Society \(ACS\) Spring Meeting](#), April 5-30, 2021.
- M.L. Meyerson and L.J. Small “Mediated Lithium-Sulfur Flow Battery for Grid-Scale Energy Storage” [239th Meeting of Electrochemical Society \(ECS\)](#), May 30 – June 3, 2021.
- T.C. Monson, T. Stevens, C. Pearce, M. Hoyt, E. Vreeland, R. Delaney, S. Atcity, B. Zheng, C. Belcher, Y. Zhou, E. Lavernia, T. Rupert “New pathways to iron nitride soft magnets” [65th Annual Conference on Magnetism and Magnetic Materials](#), November 2-6, 2020.
- T.C. Monson, T. Stevens, C. Pearce, M. Hoyt, E. Vreeland, R. Delaney, S. Atcity, B. Zheng, C. Belcher, Y. Zhou, E. Lavernia, T. Rupert “New Pathways to Iron Nitride Soft Magnets” [Magnetism 2021](#), January 19-20, 2021.
- T.C. Monson, T. Stevens, C. Pearce, M. Hoyt, E. Vreeland, R. Delaney, S. Atcity, B. Zheng, C. Belcher, Y. Zhou, E. Lavernia, T. Rupert “New Iron Nitride Soft Magnetic Components” [Applied Power Electronics Conference \(APEC\) 2021](#), June 14-17, 2021.
- N. Paudel, B. Ale Magar, T.N. Lambert, I. Vasiliev “Ab Initio Study of the Influence of Structural Defects on the Electrochemical Properties of MnO₂ in Rechargeable Zn/MnO₂ Alkaline Batteries” [Four Corners Section Meeting of the American Physical Society](#), October 23-24, 2020.
- N. Paudel, B. Ale Magar, T.N. Lambert, I. Vasiliev “Influence of Surfaces on the Electrochemical Properties of MnO₂ in Rechargeable Zn/MnO₂ Batteries” [March Meeting of the American Physical Society](#), March 15-19, 2021.
- S.J. Percival, R.Y. Lee, M.M. Gross, A.S. Peretti, E.D. Spoecke, L.J. Small “Electrochemistry of the NaI-AlBr₃ Low Temperature Molten Salt System: Implications for Applied Battery Performance” [American Chemical Society \(ACS\) Spring Meeting](#), April 5-30, 2021.

- S.J. Percival, R.Y. Lee, M.M. Gross, L.J. Small, A.S. Peretti, E.D. Spoecke "Electrochemistry of the NaI-AlBr₃ Low Temperature Molten Salt System: Implications for Applied Battery Performance" [2021 MRS Spring Meeting & Exhibit](#), April 17-23, 2021.
- L.J. Small, S.J. Percival, R.Y. Lee, M.M. Gross, A.S. Peretti, E.D. Spoecke "Molten Salt Catholyte for Low-Temperature Molten Sodium Batteries" [Materials Research Society \(MRS\) Spring/Fall Meeting & Exhibit](#), November 27 – December 4, 2020.
- L.J. Small, M.M. Gross, S.J. Percival, R.Y. Lee, A.S. Peretti, E.D. Spoecke "Materials Development for High-Performance Interfaces in Low-Temperature Sodium Batteries" [American Chemical Society \(ACS\) Spring Meeting](#), April 5-30, 2021.
- E.D. Spoecke, M.M. Gross, S.J. Percival, R.Y. Lee, L.J. Small "Implementing Low Temperature Strategies to Advance 'Really Cool' Molten Sodium Batteries" [Electrochemical Society PRiME](#), October 4-9, 2020.
- E.D. Spoecke, A.S. Peretti, E. Coker, M. Rodriguez, M.M. Gross, S.J. Percival, L.J. Small, R. Hill, Y.T. Cheng "Solid State Ion Conductors to Enable Low Temperature Molten Sodium Batteries" [Electrochemical Society PRiME](#), October 4-9, 2020.
- E.D. Spoecke, A.S. Peretti, E. Coker, M. Rodriguez, M.M. Gross, S.J. Percival, L.J. Small "Solid State Materials to Enable Molten Sodium Batteries" [Materials Research Society \(MRS\) Spring/Fall Meeting & Exhibit](#), November 27 – December 4, 2020.
- E.D. Spoecke, M.M. Gross, A.S. Peretti, S.J. Percival, L.J. Small "Hybrid Solid State 'Chaperone' Phases to Improve Solid State Sodium Electrolytes" [239th Meeting of Electrochemical Society \(ECS\)](#), May 30 – June 3, 2021.
- L. Torres-Castro "Mitigation of Failure Propagation: A Model-Based Experimental Design" [International Battery Seminar](#), March 9-11, 2021.
- I. Vasiliev, B. Ale Magar, N. Paudel, T.N. Lambert "Phase Transformations of the MnO₂ Cathode Material in Rechargeable Zn/MnO₂ Batteries: An Ab Initio Study" [March Meeting of the American Physical Society](#), March 15-19, 2021.
- R. Wittman "Correlating Materials Degradation Trends to Electrochemical Indicators in Systematic Long-Term Cycling of Commercial Li-Ion Batteries" [2020 ECS Fall Meeting](#), October 4-9, 2020.
- R. Wittman, M. Dubarry, S. Ivanov, A. Fresquez, J. Langendorf, R. Grant, G. Taggart, B.R. Chalamala, Y. Preger "Comprehensive Electrochemical and Materials Characterization of Commercial Li-ion Battery Degradation" [239th Meeting of Electrochemical Society \(ECS\)](#), May 30 – June 3, 2021.
- D. Xing, C. Xie, K. Wang, T. Liu, B. Hu, J. Wang, A. Agarwal, R. Singh, S. Atcitty "3.3-kV SiC MOSFET Performance and Channel-Length Related Short-Circuit Capability" [IEEE Workshop on Wide Bandgap Power Devices and Applications in Asia \(WiPDA-Asia\)](#), September 23-25, 2020.

ORGANIZATIONAL WORKSHOPS AND SYMPOSIA

- Sandia hosted Dr. Marija Ilić, Professor Emerita from Carnegie Mellon University, who presented at Energy and Earth Systems Distinguished Lecture Series. There were more than 55 attendees who watched her speak on "From Today's Hierarchical Control to End-to-End Flexible Interactive Electricity Services." May 26, 2021.
- DOE Long Duration Energy Storage Workshop, March 9-10, 2021 - Team led by Erik Spoerke organized a 2-day DOE workshop on Long-Duration Energy Storage (March 9-10). The meeting dramatically exceeded expectations with over 1600 registrants, 600 participants engaging multiple DOE offices, national labs, and a collection of national and international participants in academia and industry.
- Valerio De Angelis, Session Chair for "Battery and Energy Management Needs for Lithium and non-Lithium Energy Storage Systems" [IEEE Power and Energy Society \(PES\) General Meeting](#), July 26-29, 2021.
- Josh Lamb "Mitigation Strategies for Propagating Battery Failures in Pouch Cell Batteries" Interagency Power Group Chemical Working Group Safety Panel, October 2020.
- Yuliya Preger and Dr. Imre Gyuk, Organizers of the half-day tutorial "Enabling Safe Operation of Energy Storage Systems for Enhanced Resilience" for Resilience Week 2020.
- Yuliya Preger, Lead Organizer for "Symposium on Advancement of Lithium-Based High-Energy Density Batteries at Multiple Scales, Factoring in Safety" [Materials Research Society \(MRS\) Spring/Fall Meeting & Exhibit](#), November 27 – December 4, 2020.
- Yuliya Preger, Co-chair for Battery Student Slam Symposium at the [239th Meeting of Electrochemical Society \(ECS\)](#), May 30 – June 3, 2021.
- Noah Schorr, Lead Organizer for "Symposium ENO9 Advances in Conversion Electrodes for Reliable Electrochemical Energy Storage" [2021 MRS Spring Meeting & Exhibit](#), April 17-23, 2021.
- Erik Spoerke, Organizer for "Symposium on Ion Conducting Ceramics" American Ceramic Society's Conf on Electronic Materials and Applications (EMA), January 2021.
- Ujjwol Tamrakar, Session Chair for "TS-51: Modern Power Conversion Schemes for Electric Vehicles II" [30th International Symposium on Industrial Electronics \(IEEE ISIE\)](#), June 20-23, 2021.
- R.D. Trevizan, Session Chair for "Innovation and Adoption of New Grid Technologies" [IEEE PES 12th Conference on Innovative Smart Grid Technologies \(ISGT 2021\)](#), February 16-18, 2021.



Webinars

WEBINARS

- S. Atcitty “Microgrids for Resilient Electricity Systems” DOE Office of Indian Energy’s Tribal Energy webinar series, June 30, 2021.
- J. Lamb hosted “Materials Developments in Battery Safety” for an MRS webinar, May 26, 2021.
- H. Passell, et al. New Mexico Public Regulatory Commission ES Webinar Series, “Achieving NM’s Carbon Free Mandate,” Nov. 2020 – Feb. 2021 (4-session webinar)
- H. Passell, et al. New Jersey Bureau of Public Utilities ES Webinar Series, Jan. – Mar. 2021 (4-session webinar)
- Y. Preger “Ensuring Safety of Grid-Scale Energy Storage Systems” IEEE Smart Grid, September 15, 2021.
- M. Ropp “IEEE P1547.9: A New Standard to Help Streamline Energy Storage Interconnection with Distribution” New Mexico Public Regulatory Commission Interconnection Rules Revision meeting, February 18, 2021.
- M. Ropp “IEEE P1547.9: A New Standard to Help Streamline Energy Storage Interconnection with Distribution” Northeast Council of Public Utility Commissioners DOE Energy Storage Webinar Series, May 21, 2021.
- B. Schenkman and S. Atcitty “An Introduction to Energy Storage” 2020 Tribal Energy Webinar Series: Tribal Energy Project Technology Options, May 27, 2020.
- R.D. Trevizan “Cybersecurity of Battery Energy Storage Systems,” IEEE Smart Grid, March 11, 2021.

The Energy Storage Systems Policy and Outreach Program began its series of energy storage webinars with Iowa State’s Electric Power Research Center and the Organization of MISO States:

- Topics in the first session held July 31, 2020, included an introduction to energy storage, an overview of energy storage systems (Howard Passell), and an overview of energy storage policy (Will McNamara).
- Topics in the second session held August 28, 2020, included energy storage applications and value stacking (Ray Byrne) and using analytics to improve the value proposition for energy storage.
- The third session held September 11, 2020, highlighted multiple energy storage case studies.
- Topics in the fourth session held September 25, 2020, included energy storage policy and regulatory special topics (Will McNamara).
- Topics in the fifth session held October 9, 2020, included energy storage project development and energy storage finance.
- Topics in the final session held October 23, 2020, included power systems and energy storage R&D.

The Energy Storage Systems Policy and Outreach Program continued its series of energy storage webinars with the New Mexico Public Regulation Commission (NM PRC):

- Topics in the first session held November 10, 2020, included energy storage for meeting peak load in California and Nevada and policy issues for using energy storage for peak load in New Mexico (Will McNamara).
- Topics in the second session held December 8, 2020, included energy storage transmission and distribution (T&D) Deferral, a regulatory best practices and lessons learned roundtable, and the New Mexico policy perspective on energy storage for T&D deferral.
- Topics in the third session held January 5, 2021, included an Introduction to energy storage & electrification, understanding electric vehicle integration, electric vehicle adoption rates, and policy issues associated with electrification in New Mexico (Will McNamara).
- Topics in the final session held February 9, 2021, included energy storage and multiple use applications (Ray Byrne), energy storage for resilience (Bobby Jeffers), and policy and planning for resilience.

The Energy Storage Systems Policy and Outreach Program continued its series of energy storage webinars with the New Jersey Board of Public Utilities (NJBPU):

- Topics in the first session held January 25, 2021, included Introductions to Energy Storage, Energy Storage Systems (Howard Passell), Energy Storage Multiple Use Applications and Economics, Federal Energy Storage Policy Issues, and State Energy Storage Policy Issues (Will McNamara).
- Topics in the second session held February 8, 2021, included an overview of Electricity Delivery Companies (EDC), a panel discussion focused on Streamlining Interconnection (Mike Ropp), and Energy Storage Safety.
- Topics in the third session held on February 22, 2021, included an introduction to energy storage cost benefit analyses (Ray Byrne), energy storage economics (Ray Byrne, Howard Passell, Will McNamara), information on FERC orders 841 & 2222, and policy levers for making energy storage cost effective in New Jersey.
- Topics in the final session held on March 8, 2021, included the role of energy storage in supporting overburdened communities, an overview of energy storage programs in CA, NY, & MA with an emphasis on overburdened communities, information on the CA Self Generation Incentive Program, and policies supporting energy storage for Peaker plants and impacts on overburdened communities (Will McNamara).

The Energy Storage Systems Policy and Outreach Program continued its series of energy storage webinars with the New England Consortium of Public Utility Commissions (NECPUC):

- Topics in the first session held March 19, 2021, included an overview of state & federal energy storage policy and deployments (Will McNamara) and introductions to energy storage technologies (Howard Passell) and energy storage economics.
- Topics in the second session held April 2, 2021, included Decarbonization, Energy Storage, and Electrification; and CA-self Generation Incentive Program, Watt Time, and Getting Greenhouse Gases out of ES.
- Topics in the third session held April 16, 2021, included the Connecticut Green Bank Report on Cost/Benefit Analysis; MA State of ES and Clean Peak Energy Standard; and CEC Programs, State Energy Agencies Roundtable.
- Topics in the fourth session held April 30, 2021, included presentations from each of the six commissions in NECPUC (CT, RI, MA, NH, ME, and VT) and reflections on the state presentations.
- Topics in the fifth session held May 21, 2021, included streamlining interconnection (IEEE P1547.9 – Mike Ropp), fire safety codes, success stories, and measurable impacts.
- Topics in the sixth session held June 4, 2021, included federal policy and storage; FERC Orders 841, 2222, and 2222a; and an ISO New England Panel on Storage in Regional Markets.
- Topics in the final session held June 25, 2021, included CESA Policy Best Practices for NE States, and Energy Storage, Equity, and Resilience.

The Energy Storage Systems Policy and Outreach Program concluded its series of energy storage webinars with the Wisconsin Public Service Commission (PSC):

- Topics in the first session held April 28, 2021, included introductions to energy storage policy (Will McNamara), technologies (Howard Passell), and economics.
- Topics in the second session held May 12, 2021, included an introduction to energy storage benefit cost analysis (Ray Byrne) and an overview of energy storage benefit cost analysis in the United States (Will McNamara).
- Topics in the third session held May 26, 2021, included an overview of California's Self-Generation Incentive Program, getting greenhouse gases out of energy storage, and dual use policy.
- Topics in the fourth session held June 9, 2021, included project development and commissioning (Dan Borneo), interconnection and other technical issues associated with multiple use applications (Mike Ropp), and energy storage system safety (David Rosewater).
- Topics in the fifth session held June 23, 2021, included a survey of energy storage technologies spanning batteries (Reed Wittman), CAES (Steve Bauer), hydrogen, thermal (Cliff Ho), and gravity systems.
- Topics in the final session held July 14, 2021, included interconnection policy, avoiding stranded assets (Will McNamara), energy equity and energy storage, and environmental justice.

