ENERGY STORAGE ROADMAP

2022 UPDATE

Energy storage is essential to a clean and modern electricity grid and is positioned to enable the ambitious goals for renewable energy and power system resilience. The EPRI Energy Storage Roadmap vision was initially published in 2020, and significant detail has been added in this 2022 update. This document describes in detail the research activities underway to address gaps to meet to the 2025 vision.

The Energy Storage Roadmap is organized around broader goals for the electricity system: Safety, Reliability, Affordability, Environmental Responsibility, and Innovation. EPRI's energy storage research activities are connected to this Roadmap to evaluate progress in closing gaps and to guide new research activities. This Roadmap is also informed by energy storage technology advancements, commercialization progress, government research efforts, and policy initiatives.

The Energy Storage Roadmap development is a collaborative development process consisting of the following phases:

The first step was to assess the current state of energy storage across multiple dimensions, such as:

- Safety issues including fire events, safety practices, and standards and code development
- Energy storage systems and their subsystems' performance and reliability
- Economics valuation and cost projections
- Environmental responsibility encompassing the complete life cycle
- Innovation in the energy storage space that pushes product availability and adoption

External drivers of change were identified, including technology advancements, cost reductions, safety, reliability and resiliency needs, policy, and corporate and personal choice.

The working group consisting of utility advisors and the EPRI energy storage team developed 15 future states that envisioned the developed state of energy storage and identified gaps that needed to be addressed.

This Energy Storage Roadmap edition describes research activities that are ongoing and planned to close identified gaps. Each future state lists current ongoing research and the related publications and closes with a section on planned research. To see additional research supporting the advancement of energy storage, visit EPRI's StorageWiki site.

ENERGY STORAGE FUTURE STATES: 2025

These future states are collaboratively defined and periodically revisited to chart a vision for energy storage.

SAFETY	ELECTRICITY RELIABILITY	ECONOMICS	ENVIRONMENTAL RESPONSIBILITY	INNOVATION
Safety practices established *Page 2*	Energy storage asset reliability characterized and enhanced *Page 8*	Planning and operational modeling validated and applied *Page 14*	Reduced emissions with energy storage applications *Page 20*	Technology advancements accelerated *Page 26*
Asset hazards characterized and minimized *Page 4*	Energy storage controls integrated and interoperable *Page 10*	Multi-use applications enabled *Page 16*	Sustainable and equitable life cycle implemented *Page 22*	Future workforce available and trained *Page 28*
Community resilience and public safety applications viable *Page 6*	Energy storage integrated into grid planning and portfolio management *Page 12*	Total cost of ownership reduced *Page 18*	End-of-life impacts minimized *Page 24*	Cross-industry breakthroughs tracked and integrated *Page 30*

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SAFETY PRACTICES ESTABLISHED

Energy storage safety is critical to protect workers, first responders, and the public. This is accomplished through well-developed codes, standards, and best practices that are applicable for energy storage systems in normal and emergency situations. Efforts have focused on understanding hazards and mitigating risks to inform guidelines. Safety practices are promoted through data sharing, safety event forensic analysis, tool development, industry collaboration, and site and system safety evaluations.

Future State Lead: Dirk Long, *dlong@epri.com*

GAPS

Public safety guidelines: Reported safety incidents and energy storage fires highlight risks to public safety. There is limited guidance and information on the impacts of energy storage failures to the surrounding communities and on the environment.

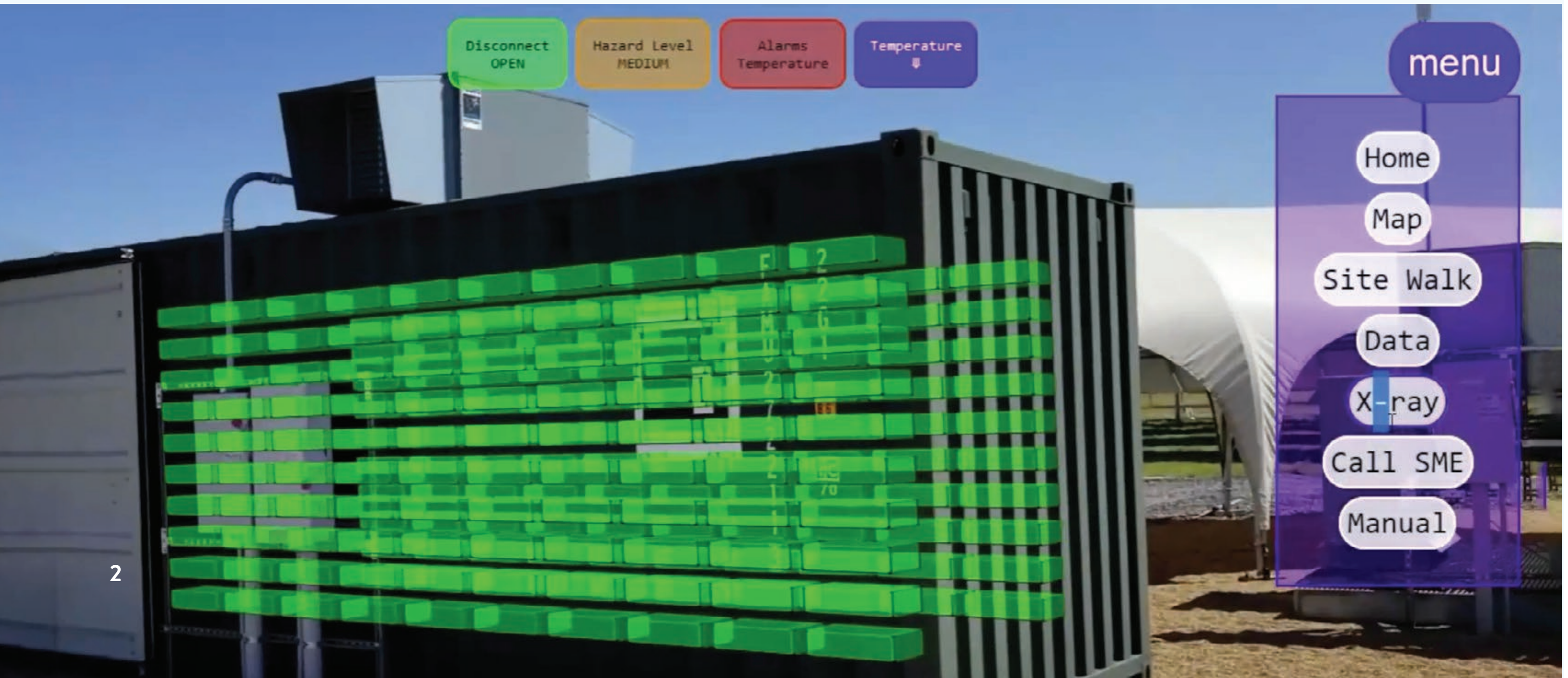
Handling, transport, and installation guidelines: Stored energy has special risks during its life cycle transitions. The handling, transport, and installation aspects of an energy storage project life cycle require guidelines and protocols. These then need to be shared to educate vendors, developers, utilities, jurisdictional officials, and all stakeholders to ensure effective safety practices.

Operator guidelines: The operations of an energy storage system impact safety. Guidelines and resources on how to safely operate an energy storage system with situational awareness of external and internal factors, such as heat waves, storms, and battery alarms, are important to reduce probability and severity of hazards. It is also important to educate and inform operators on these guidelines.

Maintenance and repair safety guidelines: Maintenance requires special attention because it typically brings personnel in close proximity to assets, which in some cases may be damaged. Maintenance safety practices are important because personnel are close to electrical, chemical, and/or thermal hazards and proper procedures and equipment are paramount. Guidelines and resources to educate and inform the industry on safety considerations for the maintenance of the energy storage system need additional development.

Incident response protocols: During an energy storage failure incident, there is need for both speed and care in the response to the event to mitigate its severity and protect lives. Comprehensive resources and training for the industry on best practices for handling and evaluating an incident are needed to ensure the safety of responders and the public within the vicinity of the failed system, to work to minimize damage to the energy storage system, and to manage environmental response aspects such as fire water runoff, chemical spills, and air quality.

Design and manufacturing safety practices: The design basis of energy storage components, systems, and installations should use a "fail safe" design process. Further, best practices need to be identified to guide battery manufacturers, energy storage system integrators, utilities, and developers in the applicability of codes and standards.



CURRENT RESEARCH PRIORITIES

Incident and Lessons Learned Tracking: A public database of energy storage system failures was developed and is managed by EPRI to bring awareness to incidents that occur around the globe. Further, EPRI is working closely with members to collect incident data and reconstruct how and why the incident began, to understand its progression, and to inform research, design guidance, and update resources.

Battery Energy Storage Fire Prevention and Mitigation: Phase II: The second phase of the Fire Prevention and Mitigation supplemental research project began in late 2021. This collaborative project conducts research as prioritized by the Battery Fire Safety Roadmap and participant input to create an Energy Storage Project Lifecycle Safety Toolkit. This toolkit will include resources such as data sets, calculators, white papers, guideline documents, and a decision framework tool to enable a safe energy storage deployment plan. This project also gathers leading practices through active engagement with industry stakeholders including utility SMEs, fire protection experts, codes and standards organizations, authorities having jurisdiction (AHJs), and other research organizations. (SPN: Battery Energy Storage Fire Prevention and Mitigation: Phase II)

Battery Firewater Composition and Risk Assessment: This supplemental project addresses the water composition resulting from the use of water as a battery fire suppressant and estimates subsequent environmental transport. The results will inform future risk assessments and emergency response planning. (SPN: Battery Firewater Composition and Risk Assessment)

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
Battery Storage Fire Safety Roadmap*	Roadmap for safety research building from Phase I of the Fire Prevention and Mitigation Supplemental Project.
BESS Failure Event Database*	Online public resource that is managed with public information on BESS failure events across the globe. This resource is accompanied by an e-mail alert notification list for new events as they are added to the database.
Lessons Learned: Lithium Ion Battery Storage Fire Prevention and Mitigation—2021*	White paper update on the key findings from Phase I of the Fire Prevention and Mitigation Supplemental Project.
ESIC Energy Storage Safety Incident Gathering and Reporting List*	A list to help frame appropriate questions and develop a template for database entries that would further support the identification of common failure modes and characteristics of the incident.
Design Trade Study Method for Battery Energy Storage Fire Prevention and Mitigation	Proposed method of assessing the trade-offs in energy storage system design between those that address hazard prevention and those that allow for controlled failure.
Proactive First Responder Engagement for Battery Energy Storage System Owners and Operators	A brief that serves as a starting point for discussion on how BESS owners/operators can proactively interact with first responder organizations, focused on preparatory pre-incident planning.

* Free to Public

FUTURE RESEARCH PLANS

SSPARTA: The Storage Safety Performance and Reliability Technology Accelerator is a broad effort being socialized to align work and leverage efforts and resources to accomplish investigation and data analysis in safety.

Energy Storage Project Life Cycle Safety Toolkit. This toolkit will continue to expand as more long-term issues are addressed as outlined in the Battery Storage Fire Safety Roadmap.

BESS Augmented Reality Maintenance and Safety (ARMAS) Case Study: This project will build off the initial augmented reality demonstration to develop a working system with use cases within the energy storage maintenance and safety event response context through working with a real-world system.

Safety Updates for ESIC Energy Storage Guides: Through further safety research, the ESIC guides will be updated to include best practices and be informed by lessons learned to facilitate more effective procurement, deployment, and operations of energy storage to manage safety risks.

ASSET HAZARDS CHARACTERIZED AND MINIMIZED

The general knowledge and understanding of energy storage technology hazards has developed rapidly in recent years, but additional work is needed to address these hazards and adapt for evolving technologies. This future state aims to characterize and mitigate hazards with informed and comprehensive approaches to reduce the probability and severity of failure events.

Future State Lead: Taylor Kelly, *tkelly@epri.com*

GAPS

Battery thermal runaway characterization and mitigation: One specific and urgent gap is understanding thermal runaway, specifically of lithium ion batteries, which are the dominant technology in current energy storage system deployments. The industry needs broad and public testing of batteries and systems to characterize this hazard of the various chemistries and form factors. A proper understanding of the hazard will enable effective mitigation strategies to be designed, validated, and deployed.

Siting risk management practices: Siting energy storage systems and understanding their associated hazards is new to storage developers, installers, owners, and insurers. Studies and tools are needed to better understand and effectively mitigate against site-related hazards. Sharing lessons learned and experiences will help develop leading siting, deployment, and insurance practices.

Emerging storage technology safety information and analysis: Although lithium ion technologies are the dominant form of energy storage systems for now, the hazard landscape is constantly evolving with new chemistries as well as new forms of stationary energy storage being developed. These new technologies will have different hazard profiles that need to be thoroughly understood to be effectively mitigated.

Failure modes and effects analyses (FMEA): A systematic hazard analysis is an effective process for enabling the deployment of safer systems through comprehensively addressing the associated hazards. FMEA is a standard methodology that energy storage developers need to incorporate into their practices to address the types of hazards of the various technologies and to develop effective mitigation strategies.

Fire hazard testing and models: Due to the hazards associated with storing energy in many formats, a fire and potential uncontrolled release of that energy is possible. To effectively mitigate fires and energy release, large-scale fire testing should be conducted. Modeling of the different technology fire risk profiles can be an alternative to the high costs of individual tests. These models can be input into tools that can inform all aspects of the project life cycle, such as siting, design, construction, operations, and incident response.

CURRENT RESEARCH PRIORITIES

Developing Fire Hazard Analysis Framework. A current activity in ESIC supporting energy storage safety is the development of a fire hazard mitigation analysis framework for understanding and communicating strategies to be used to mitigate hazards or minimize the consequence of an event. EPRI's Energy Storage Integration Council is an open, technical collaboration of industry stakeholders that creates publicly available resources to support energy storage deployment.

Battery thermal runaway propagation testing reporting: Mitigating energy storage systems thermal runaway requires a better understanding of it and its possible propagation. The energy released from one failed cell can induce failure in neighboring cells, and an understanding of this can inform the engineering design of the system to prevent propagation from cell to cell, module to module, rack to rack, or container to container. EPRI is reporting on testing of thermal runaway along with propagation testing.

Fire prevention and mitigation supplemental project, Phase II: This collaborative project is conducting research as prioritized by the Battery Fire Safety Roadmap and participant input to create the Energy Storage Project Life Cycle Safety Toolkit. Specifically, a design trade-off study of an energy storage system relocation is being undertaken and guidelines for use of FMEA or other similar tools are being developed. Another project is plume modeling.

Environmental and safety aspects of asset hazards: Investigations of the human health and environmental impacts associated with energy storage system hazards is necessary to understand the full range of possible externalities, improve safety, inform risk assessments, and design mitigation approaches. These issues may include chemical or combustion releases to environmental media, toxicology, or epidemiological assessments or other health and safety determinations.

Battery Firewater Composition and Risk Assessment: Analysis of water composition of runoff when water is used as a fire suppressant and potential impact on ground water. This work will inform future risk assessment and emergency response planning.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
ESIC Energy Storage Reference Fire Hazard Mitigation Analysis*	A common hazard mitigation analysis format and language to improve confidence among stakeholders when developing, procuring, and operating safe energy storage systems.
Near-Field Air Modeling Tools for Potential Hazardous Material Releases from Battery Energy Storage System Fires	Summary of the literature estimating the GHG impacts resulting from various battery energy storage deployment and operational scenarios.
Air Modeling Simulations of Battery Energy Storage System Fires	Plume modeling dispersion scenarios in several geographic locations, with varying meteorological conditions and storage facility designs, were run and analyzed to understand extent and magnitude of pollutant transport.
BESS Explosion Hazards White Paper*	White paper describing the basics of explosion hazards and how failures in lithium ion systems can cause explosions, including the quantity and species of flammable gases produced by thermal runaway and a simple formula to determine how much energy stored in failing cells is required to create an explosion hazard for a given room volume.
ESS Explosion Hazard Calculator Tool	Explosion hazard calculator allowing the user to utilize characteristic data from battery failure testing to conduct preliminary NFPA 68 and NFPA 69 calculations for initial, non-design-related assessments.
Lithium ion Battery Thermal Runaway Propagation and Emissions Analysis	Thermal runaway and propagation testing of lithium ion battery modules through overheating. The purpose of this study was to understand the dynamics and conditions of thermal runaway, incident evolution, and interaction with the surrounding environment.
EPRI Lithium Ion Battery Module Burn Testing Annotated Video	Video conveying hazards and hazard sequences that may be present during a failure within an energy storage system that results in thermal runaway.

* Free to Public

FUTURE RESEARCH PLANS

SSPARTA: The Storage Safety Performance and Reliability Technology Accelerator is a broad effort being socialized to align work and leverage efforts and resources to accomplish investigation and data analysis in safety.

Guidelines and lessons learned: Battery energy storage system failures have been on the rise. Understanding why these systems failed and assessing responses can inform the industry, mitigate future events, and develop effective responses to an event.

Beyond lithium ion: New and emerging energy storage technologies are being developed and demonstrated. It is important to understand the safety hazards throughout the project life cycles of these new energy storage technologies and products.

COMMUNITY RESILIENCE AND PUBLIC SAFETY APPLICATIONS VIABLE

Electric service continuity for customers and communities has become more important due to the use of technologies that are relied on for the safety of everyday life. Energy storage solutions are increasingly called upon to provide power continuity services to support resilience applications for storms, disasters, and disruptions. Energy Storage products and services will reflect geography, load served, duration, and criticality for customer and community power continuity to ensure safety.

Future State Lead: Nick Tumilowicz, *ntumilowicz@epri.com*

GAPS

Quantification of resilience value for communities: Resiliency use cases need to be identified so that the community power continuity needs can be documented, which can lead to determining best methods to assess the community resilience value. Utilities and customers are installing and using resiliency products and services to provide continuous power through scheduled and unscheduled power outages.

Energy storage public safety use definition: Definition and categorization of types of public safety events within a matrix identifying how energy storage can help ensure resilience will lead to better products. Energy profiles of community centers, emergency shelters, government buildings, and individual residences are inputs into defining public safety energy storage use cases.

Community and customer resilience options awareness: Customer resilience solutions are not well understood by communities and industry today. Technologies and their ability to ride-through events, provide extended support, and perform across different environmental conditions need to be evaluated, catalogued, and tested. Designs, locations, configurations, and system integration need to be understood to develop a library of options to meet specific community needs. These solutions can span from "camping" batteries to large-scale microgrids integrating solar, energy storage systems, and electric vehicles.

Coordination of customer and utility assets: As the exponential growth of customer energy storage solutions for resilience continues, characterizing the additional value enabled by providing grid services through coordination has become increasingly important. Initiatives such as FERC Order 2222 are laying the groundwork toward enabling market mechanisms to ascribe value to energy storage and its co-located resources including solar and electric vehicles. Defining business models and technical approaches to connect and manage these assets on a day-to-day basis—especially when resiliency is needed—is critical to ensure that flexible resources are used and optimized for communities and the electric system.

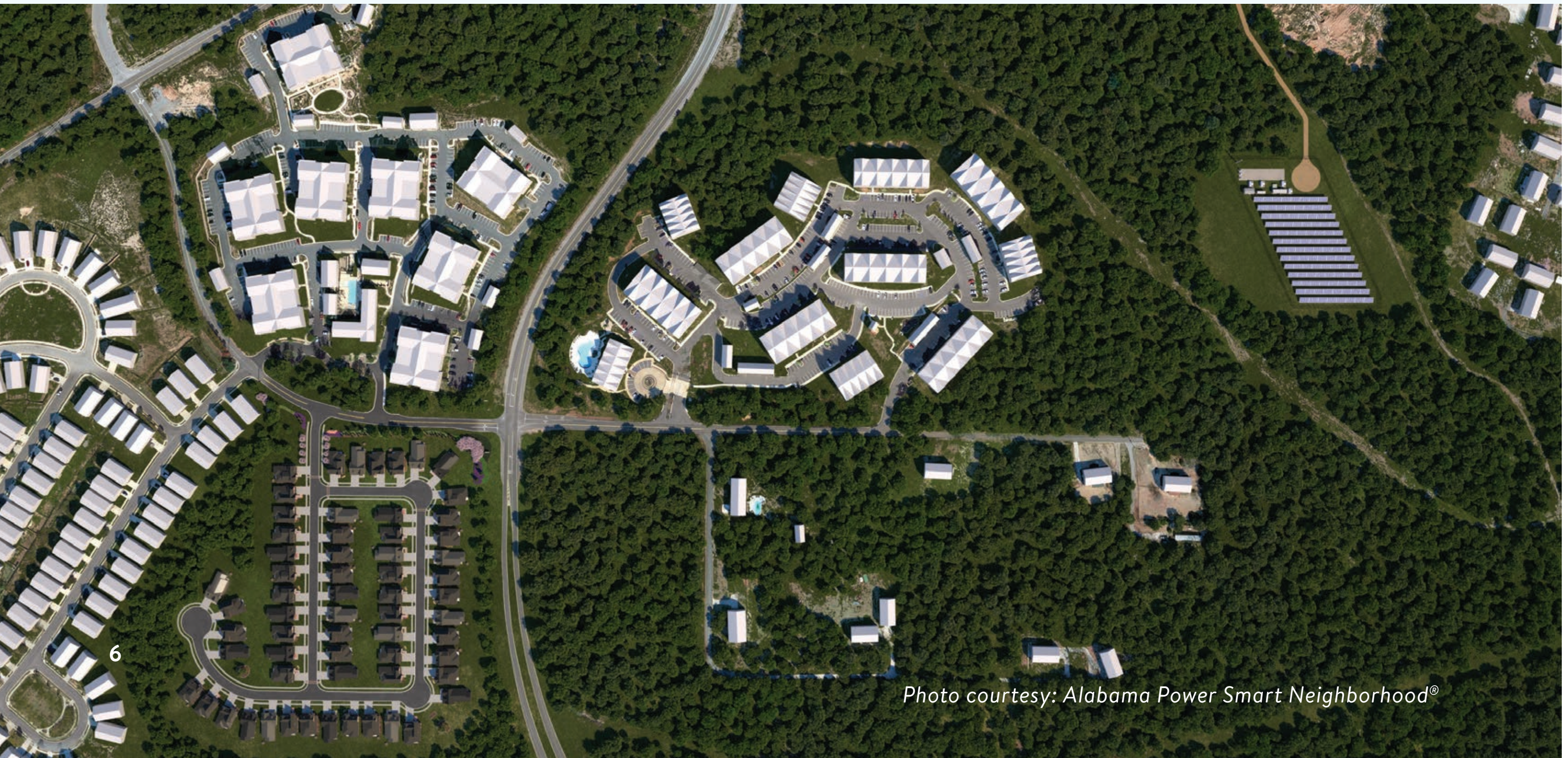


Photo courtesy: Alabama Power Smart Neighborhood®

CURRENT RESEARCH PRIORITIES

Technology evaluation and product testing: The existing and future technologies are closely tracked and, through the Energy Storage for Customer Resilience project, they are tested and validated to provide objective information about their installation, operation, and performance under various conditions. This provides understanding of their capabilities for resilience, demand response, and grid services.

Project applications and economic analysis: Different approaches to increasing community resilience are evaluated, at the same time optimizing the financial aspects by using the available incentive programs, time-of-use tariffs, algorithms, or other opportunities.

Utility-customer program evaluation, harmonization, and industry business models: Evaluation of utility-customer programs provide insights on industry business models. Attention is on financial aspects as well as impacts on the customer and the grid.

Value of resilience interest group: EPRI convenes a forum of stakeholders to identify technical approaches and use cases for resilience valuation. The group leverages EPRI's collaborative approach and engages a broad group of stakeholders to accelerate learning on various resilience choices and investments, starting with estimating the costs of long-duration outages to customers.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
Economics, Resiliency, and Customer-Utility Programs	A report on the economic aspects of using various solutions to increase resilience. Incentive programs for customers offered by utilities are evaluated.
Customer Energy Storage Technology, Economics, Deployments	Assessment of state-of-the-art customer-sited energy storage products, projects, vendors, and capabilities. Resilience, reliability, safety, codes, and standards as well as shared benefit streams are discussed.
Wildfires and Public Safety Power Shutoffs: Distributed Energy Resources for Community Electricity Resilience*	Introduction to society's growing wildfire concerns, including interactions with the electric power system and implications to electric power resilience, particularly in California and similar climates.
Decarbonizing Edge-of-the Grid Resilience Solutions: Microgrid Techno-Economic Analysis	White paper exploring a techno-economic analysis framework for microgrids. It lists available microgrid generation sources that can help successfully meet both decarbonization and resilience goals.
Transportable and Mobile Energy Storage, Use Cases, and Applications	Overview of transportable or mobile energy storage (TMES), an emerging type of ESS design that can be easily relocated and redeployed at different locations, and a range of use cases that energy storage can provide such as customer resilience.
Energy Storage Product Database v1.0	A dynamic platform providing up-to-date technical specifications and market applications related to key energy storage products and systems.

* Free to Public

FUTURE RESEARCH PLANS

New product introduction design and performance testing: Using the experience in product testing to date, EPRI intends to continue work on the verification and testing of designs and the operation and capabilities of new products.

Customer resilience solutions for medical customers: Leveraging its expertise in customer energy storage and program design, EPRI will evaluate solutions, validate performance, and harmonize utility programs to support customers needing electricity to maintain their quality of life.

Low carbon distributed generation demonstration: Utilities have a significant high-carbon diesel asset base to support resiliency. This research project will validate the use of sustainable ethanol fuel with this asset base as an alternative to determine performance and emission profiles.

ENERGY STORAGE ASSET RELIABILITY CHARACTERIZED AND ENHANCED

For energy storage to be fully capable of providing utility and customer resilience and enhanced electric system reliability, its performance needs to be consistent and predictable. This includes highly dependable performance supported by accurate asset health tracking. Independent assessment and standardized reporting will give confidence to utility planners, operators, and users.

Future State Lead: Steve Willard, *swillard@epri.com*

GAPS

Operational data availability, uniformity, and accuracy: Energy storage performance is difficult to grasp due to the many manufacturers, technologies, system sizes, and their applications because there are no standardized data requirements. Data standardization is coming and will evolve, and research can inform the process to enable more data accuracy and uniformity. A more uniform data stance—with wide availability of data down to the component level—could allow for better knowledge of energy storage system performance and its reliability. Standardized data processes, descriptions, and labels need to support data collection to be effective and consistent. Data collection and their transfer systems also need to be capable of acquiring large quantities of data on a prescribed time granularity using accurate and precise sensors and meters and be detailed in standards. Appropriate and timely data are vital for fuller understanding of energy storage system operational risks. Energy storage operational metrics need to be akin to a typical rotating machine resource with sensors and monitors that provide accurate data collection and analysis to ensure that energy storage assets are safe and reliable.

Analysis and benchmarking of available technology data: Advanced data analysis approaches are being developed and implemented to assess performance, allow similar system comparisons, and improve predictability of performance, downtime, and maintenance requirements. Methods to evaluate both non-numeric and numeric data are necessary to derive standard reliability indicators such as system availability, forecasted efficiency, and failure rates. Other data assessment capabilities needing development include component- and system-level failure rates to be able to identify weak components, allowing for improved reliability.

Reliability models for utility planners and operators: Utility planners and operators require accurate performance and reliability information on individual units and fleets of energy storage assets to precisely reflect storage grid impacts. Two critical energy storage system data points for power system reliability models and system operators are the state-of-charge (SOC) and state-of-health (SOH). There are various methods to calculate SOC and SOH, which include vendor proprietary algorithms; different battery chemistries require different approaches leading to discrepancies in calculated values. More research is needed to determine which methods reflect actual values most accurately for specific battery chemistries and operating profiles.

O&M practices: Maintenance planning is critical to ensuring asset reliability; however, with limited operational experience and data, leading maintenance practices are still under development. These O&M practices need to be derived from an abundance of uniform field data to attain efficient, reliable, and safe operations. A standardized O&M platform that digitally collects field data would provide input for corrective actions, planned maintenance, and identification of poor-performing components as well as support field technicians when energy storage systems experience outages along with lowered operational costs and increased reliability.

CURRENT RESEARCH PRIORITIES

Provision of interim energy storage reliability findings: EPRI is sharing findings from Phase 1 of the Energy Storage Performance and Reliability Data Initiative with standards organizations and other interested stakeholders. Field assessment and data analysis findings are available to develop best performance and reliability practices as standards and reporting guidelines are being developed.

Expanding EPRI's Performance and Reliability Initiative: EPRI has launched a Phase II project to collect and manage field asset performance and reliability data, extend data analysis capabilities, and enhance user interfaces to assess and compare energy storage systems as soon as data are available. In addition, performance prediction indicators are being developed to provide foresight to expected performance and allow similar system comparisons across the industry.

Disseminating EPRI's ESIC O&M data gathering tool: EPRI is building and distributing a publicly available O&M metrics data sets tool. It is being developed and shared with field technicians and other stakeholders.

Engaging standards and rulemaking bodies: EPRI is working to provide performance assessments and findings to standards organizations and rulemaking bodies to support informed guidelines and policies. EPRI is also collaborating with the DOE to publish data guidelines on a frequent basis. Regular forums with interested parties will assist in informing activities and developing standards and rules.

Vendor capabilities: There are many vendors in the energy storage landscape. EPRI is developing an Energy Storage Vendor Database that will provide a company profile of vendors' capabilities with links to the associated Energy Storage Product Database.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
Energy Storage Performance and Reliability Foresight*	White paper that describes energy storage performance metrics, the differences between vendor and independent data findings, and how energy storage provides visibility to electric system operators in contrast to traditional utility assets.
Electrical Energy Storage Data Submission Guidelines Version 2*	Guideline on performance data requirements that discusses best practices for acquiring data needed for accurate performance assessments. Co-published with USDOE/Sandia National Laboratories.
Performance and Reliability Impacts on Modeling, Planning, and Operations	Technical brief that informs techno-economic and physical system modelers on energy storage performance impacts based on field experience and the associated data collected.
Energy Storage Performance and Reliability Foresight in StorageWiki	Online platform for quick access to field data and performance analysis results including capabilities to compare similar systems and forecast performance.

* Free to Public

FUTURE RESEARCH PLANS

Enhance energy storage degradation forecasting: In collaboration with entities such as the DOE, approaches using advanced artificial intelligence for predictive battery degradation are being assessed. Using EPRI's past learnings and access to expanded field data sets as well as laboratory and manufacturer data, robust analysis can be developed to understand characteristics of different lithium ion chemistries, applications, and system configurations. Accurate predictions of degradation will be key to efficient implementation of storage, from both a modeling and operations perspective.

Enhance storage reliability assessments: The infancy of the storage fleet precludes firm knowledge and statistically valid assessment of key reliability metrics such as availability and component failure rates. To bridge this knowledge gap, reliability models that EPRI has successfully used for traditional utility assets can create a framework to accommodate energy storage. This involves the development of a central repository of operational data, using standardized data tools and approaches. As more data are accumulated, the confidence in reports from this repository of storage data will allow for firm operational knowledge and instill leading operational practices.

ENERGY STORAGE CONTROLS INTEGRATED AND INTEROPERABLE

Energy storage control and management systems are the key to unlock the full potential of energy storage. This future state focuses on control systems that facilitate successful interoperability with existing and new grid infrastructure to support predictable, reliable, and flexible operations.

Future State Lead: Lakshmi Srinivasan, *lsrinivasan@epri.com*

GAPS

Open standards for communications and controls: IEEE and other major standards organizations are developing and refining definitions of energy storage functions and interoperability with other device- and system-level control systems (distributed energy resource management systems [DERMS], aggregation platform, and virtual power plant controls). These standards are not regularly specified in proposal requests nor have been adopted by product developers to the level needed. There is a lack of transparency in control algorithms and design architectures, affecting performance, reliability, and safety.

Cyber security: Standards and guidance for cyber security related to energy storage is lagging. Remote connectivity and vendor access to energy storage systems is a concern to the grid's safe operation because it conflicts with security utility requirements. Other issues to address include remote firmware upgrades, fleet operations, and management because they need to be compatible with critical infrastructure security requirements.

Emerging technologies and new controls functions: There is growing interest in emerging and long-duration technologies, including seasonal storage. New technologies may require different algorithms for state of charge (SOC) and degradation management as well as other maintenance operations. The application of long-duration energy storage will require control functions that are yet to be developed.

Controls longevity and continuity: Control system platforms need to be flexible because the future is uncertain. Disruptions related to company acquisitions or their going out of business need to be considered when designing and choosing controls platforms and infrastructure. Software companies can be short-lived, and they don't necessarily consider 20-year lifetimes for their products. Maintenance and backward compatibility need to be addressed. The emergence of new markets and applications will require continuing controls developments.

Energy storage fleet controls: Controls for mass deployment of large transmission battery energy storage systems are needed. Energy storage control commands and associated parameters should take guidance from traditional utility generation control standards and methods. For example, when a traditional generator loses communication with the control center, it will operate at the last known setpoint. How should energy storage system control be developed under a similar situation? It has been seen that a battery energy storage system may stop operating if the next dispatch point is unknown, which could limit its reliability as a utility resource.

CURRENT RESEARCH PRIORITIES

Catalog of control system architectures: A catalog of control system architectures and energy management systems is being developed. Safety and reliability considerations will be included.

Standards and rulemaking bodies engagement: There is engagement with IEEE committees developing standards and best practices for battery and energy management systems. Because there are constant changes in the energy storage landscape, regular forums with these groups will assist in informing standards and rulemaking activities.

Cybersecurity research: Investigation of energy storage–related security risks, including mitigation approaches for security hazards, and development of decision frameworks to prioritize mitigations.

FEATURED RESOURCES

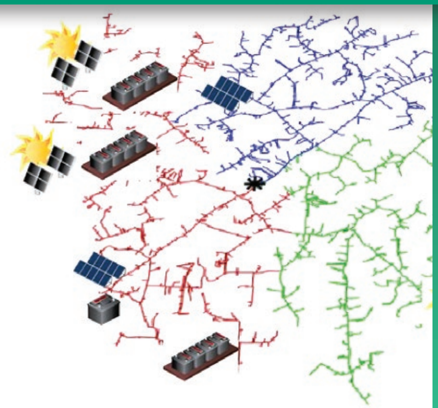
DELIVERABLE	DESCRIPTION
Landscape of Commercial Control Technologies for Energy Storage	Results of survey sent to energy storage control vendors to learn the landscape of control technologies for storage and supported functionalities and identify potential gaps that affect the value of storage projects. The main topics of this survey are technology maturity, architecture, use cases, advanced algorithms, and energy market applications.
Summary of Energy Storage Control Performance Metrics*	Performance metrics that evaluate the performance of battery storage controls when providing different grid services are discussed. The value of energy storage is directly tied to the ability of the controller to meet the desired objectives.
Overview of Energy Storage Controls: Challenges and Research Directions	Overview of different energy storage management approaches such as schedule-based, rule-based, and model-based, with a case study that includes distribution objectives and customer economic objectives comparing the effectiveness of different approaches.
Energy Storage Management Functions to Address Grid and Customer Services: Phase 2 – Information and Communication Capabilities	Assessment of the landscape for energy storage protocols and relevant communication architectures, evaluation of standards and protocols adoption depending on system location and application, and assessment of whether each protocol supports the functional specifications previously developed.
Cybersecurity Considerations for Distributed Energy Storage	This report investigates cyber security aspects for energy storage system models for utilities based on ownership, services provided by ESS, access level, and point of interconnection.

* Free to public

FUTURE RESEARCH PLANS

Standardized controls requirements: Currently controls integration and operation are custom. For widespread use and cost-effective energy storage, standardized controls requirements are needed. Standardized controls requirements are being developed for use in procurement documents that consider interconnection, project configuration, technology, and use cases among other characteristics.

Emerging technology controls: As new technologies and grid applications emerge, technology-specific controls will be identified and new methods developed to evaluate controls across technologies and vendors.



ENERGY STORAGE INTEGRATED INTO GRID PLANNING AND PORTFOLIO MANAGEMENT

Energy storage is included in electric utility planning processes as a standard power system asset. Energy storage unique characteristics, capabilities, limitations, and performance capabilities need to be accounted for in utility planning and asset management practices. Results will augment system reliability objectives at the generation, transmission, distribution, and customer levels.

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GAPS

Generation and transmission reliability planning: Energy storage can support resource adequacy and both near- and long-term capacity planning, provide system inertia and frequency response, and contribute to black-start restoration plans. Analysis methodologies for these services are under development and need to be validated and integrated into standard planning processes.

Distribution reliability planning: Energy storage can serve as a grid-hardening resource that could improve system reliability; however, the analytical methods to evaluate reliability benefits are not well developed or documented. The industry needs system application verification before confidently using energy storage to meet reliability objectives. Moreover, there is a need for screening criteria to identify potential candidate distribution feeders where energy storage can provide reliability support.

Energy storage analysis integration into standard planning processes: Energy storage, with its multi-functional capabilities, supports many services required for reliable grid operations. Some of these include non-wires solutions for transmission or distribution line and transformer upgrades, mitigating congestion, managing for voltage control, providing grid flexibility with more renewable generation deployment, and inclusion in microgrids. Analysis frameworks and methodologies have been developed and need to be tested, refined, and validated.

Asset management strategies: Utility energy storage assets need comprehensive, fleetwide management practices based on core battery technology, inverter manufacturer, controls systems, and how they integrate with other grid assets. Other concerns to incorporate into asset management strategies are component and system replacement and upgrade priorities, data monitoring for input to situational awareness that is incorporated into planned maintenance schedule, and activities to minimize reliability risks to the power system.

System and portfolio planning tools and methods: Approaches for utility or regional energy storage planning to identify locations and value streams for specific applications are developing to provide information for decision making in systemwide energy storage deployments.

CURRENT RESEARCH PRIORITIES

Energy storage studies in transmission operations and planning: Resource adequacy with stand-alone and hybrid energy storage systems is becoming more important as renewable generation penetration increases and fossil plants are retired. Long-duration energy storage capacity planning studies are becoming more relevant as technology matures. Energy storage as transmission non-wires solutions and as a black-start unit supports NERC reliability and performance requirements.

Energy storage incorporation in software to support distribution operations and planning: Support development of DRIVE and ADAPT tools to support energy storage incorporation into distribution portfolio planning, evaluate electric utility non-wires solutions, and evaluate effectiveness of energy storage to increase PV hosting capacity for site-specific and regional objectives. Use EPRI DER-VET within distribution methodologies to support economic impact assessments in distribution planning. Evaluate resilience scenarios that contain energy storage, such as pre-installed interconnection hubs.

Energy storage analysis framework for utility service territory deployment: Energy storage is expected to be a core enabler of the modern electric system. As a result, utilities are considering energy storage for both transmission and distribution system applications ranging from targeted systemwide deployment levels as part of regional goals or mandates to customized applications such as a non-wires solution. Utility planners require comprehensive and systematic analysis approaches to identify and evaluate the efficacy of various storage applications. (SPN)

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
Distribution Energy Storage Modeling for Planning 2018: Analytical Framework Demonstration Through Case Studies	This research effort is a part of longer term objective of providing utility engineers and planners with tools to evaluate ESS benefits in distribution operations and embed the analysis methodology into the planning process.
Program on Technology Innovation: Energy Storage in Resource Planning and Wholesale Markets—2021 Survey: Part II: Long-Term Economic Valuation and Research Needs	This report on energy storage in planning, operations, and markets has two parts. Part I, published separately as EPRI report 3002012300, provides a review of technology costs, historical market valuations, and other policy and commercial trends. Part II, this report, examines methods and recent studies related to planning and valuation for future storage expansion.
Transmission Planning Considerations for Energy Storage: Site Specific Use-Cases and Long-Term Planning Methods	This report discusses how short-term planning applications of energy storage on the transmission system can be studied by modifying and adapting existing planning practices. It also describes the different methods and tools required for long-term planning.
Long-Term Planning Considerations for Hybrid Renewable Generation and Energy Storage Resources	This report considers challenges in evaluating hybrid resources in resource planning and explores approaches to addressing them, followed by a survey of motivations for development of hybrid resources.
Assessing System Reliability Impacts with NWA: Guidance on Assessing NWA as Grid Hardening Resources	This technical update provides guidance on evaluating the potential reliability benefits that NWAs can provide on distribution feeders. It also investigates the influence of specific feeder characteristics on the NWA predictive reliability analysis to help identify candidate feeders for deploying NWAs. Lastly, simulation results for three utility use cases are presented in this technical update, and lessons learned are summarized.

FUTURE RESEARCH PLANS

Understanding energy storage analysis tools and integrating them into standard planning processes: A Wiki website will be developed and house present and historical energy storage analysis case studies that will describe which modeling approaches and tools were used. This will provide better representations of battery degradation, asset management, and cost modeling.

Researching performance and reliability of energy storage systems for input to modeling and planning activities: Topics include SOC and state of health (SOH) calculation methodologies, data needs for modeling and planning, and comparing field experience to modeled performance. These inputs to modeling and planning may vary over the storage lifetime and need to be accounted for.

Evaluating mobile and transportable energy storage within distribution planning: Supplemental project plans are in place to evaluate and demonstrate mobile and transportable energy storage to support backup power and distribution support in multiple scenarios, including evaluation of the resource potential in distribution reliability planning.

PLANNING AND OPERATIONAL MODELING VALIDATED AND APPLIED

Robust tools, models, and methods support planning and operations to incorporate energy storage to provide economic benefits while enhancing system reliability and resilience. Energy storage strengths and limitations will be accurately accounted for with good and validated data for single and hybrid system uses and include performance degradation. Planning addresses policy goals, emerging grid services, future loads, and generation scenarios. Energy storage siting will consider all domains, including transmission, distribution, and customer locations.

Future State Lead: Miles Evans, *mevans@epri.com*

GAPS

Benchmarking modeling vs. operational experience: A gap between modeled energy storage economics vs. real-world experience exists. Benchmarking modeled energy storage use against operational systems can reinforce opportunities to maximize value and understanding as well as improve future modeling.

Modeling sophistication and standardization: Operational models are being developed to inform planning, but they lack sophistication and standardization. A challenge of modeling energy storage is that control approaches are typically proprietary and nonstandard, so the operational response to scenarios may be difficult to predict in modeling. In addition, energy storage technologies are diverse and changing, which adds difficulty.

Valuation of long-duration storage and hybrid systems such as solar-plus-storage: Clean energy goals exemplify the need for long-duration energy storage (LDES) and hybrid system research. Analysis is needed to guide decision making on investments, application choice, and benefits to ensure that costs are **minimized.**

Accurate data for modeling: Good modeling depends on good inputs. Energy storage data are often proprietary, error-prone, or otherwise unavailable. Energy storage model parameters—such as degradation and turndown efficiency curves, temperature derating, and upfront and ongoing costs—can make a large difference in model results yet are often the subject of guesswork in the planning phase of a project. Standard, well-validated approaches to determine or estimate these case-specific values need to be developed and applied.

CURRENT RESEARCH PRIORITIES

Energy storage analysis framework: An expansion of the Analysis Framework is being addressed in a supplemental project on deployment targets or goals within a utility's service territory. An integrated planning framework and analytics to guide utility territory-wide energy storage application and technology selection and analysis will be tested and refined. Evaluation processes will guide transmission and distribution planners in their analysis of energy storage system deployment in terms of their priorities consisting of locations, services, operations, resilience, and value.

DER-VET™: EPRI's Distributed Energy Resource Value Estimation Tool is a platform for calculating, understanding, and optimizing the value of distributed energy resources (DER) based on their technical merits and constraints. DER-VET assesses site-specific energy storage and other DER technologies. It uses load and energy storage system data to identify size, duration, and other characteristics for optimizing benefits based on site conditions and the value provided from specific use cases. This is a free, publicly accessible, open-source software tool. ESIC has a DER-VET task force that meets monthly. In addition, the DER-VET User Group recently launched Supplemental Project Notice Distributed Energy Resource Value Estimation Tool (DER-VET) User Group.

Tracking and benchmarking modeling software: EPRI works with utility members to apply and benchmark near-term T&D planning tools that study operational issues and long-term planning to support investment decisions.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
Energy Storage Analysis Supplemental Project Report, Finding, Designing, Operating Projects, and Next Steps (2018–2021)*	This report provides grid planners and operators with an energy storage analysis framework to evaluate how they can be used as part of their asset portfolio, where they can be located, and how to value them.
Energy Storage in Resource Planning in the United States: 2020 Survey of Recent Results and Methods	Survey examining over 100 recent resource plans to highlight trends in ESS selection by state and region as well as collect data on assumed technology costs, attributes, and modeling tools.
Battery Energy Storage Installation Cost Estimation Tool	Tool for energy storage cost estimation that allows users to estimate installation cost for different sizing configurations and supports project cost-benefit analysis.
Solar Plus Storage Cost Assessment and Design Considerations	This study evaluates market applications and costs for paired solar-plus-storage systems. It emphasizes the importance of the full life cycle cost of paired solar-plus-storage projects and provides estimates for turnkey installed costs, maintenance, and decommissioning costs.
Battery Energy Storage System Degradation Modeling in Planning Tools: Discussion and Practical Implementation	This technical update examines the current state of degradation modeling in planning tools, how current tools consider contractual limits on operation, how current tools implement degradation-aware optimal operation, and what needs to be done in the future to enable better degradation-aware BESS planning.

* Free to Public

FUTURE RESEARCH PLANS

Modeling battery degradation: Modeling capabilities for battery degradation are expanding and being incorporated into models to be used in operational and planning decision making. An improved understanding of how energy storage degrades and the best ways to locate, size, and operate storage will enable more efficient implementation and help align current modeling with real-world practices.

Modeling long-duration storage: A new class of long-duration energy storage technologies is emerging, some of which requires expanded modeling capabilities due to their dissimilitude with lithium ion batteries. Different technical operating and sizing details along with dramatically different use cases mean that, in many cases, long-duration energy storage cannot be well-captured by traditional energy storage modeling techniques. EPRI is leading the development of modeling long-duration energy storage capabilities for these reasons.

MULTI-USE APPLICATIONS ENABLED

Energy storage has the potential to provide multi-use services that can benefit distribution and transmission grid operators as well as residential and/or commercial customers. This future state addresses decision-making tools to maximize the economic value that energy storage resources could provide through stacked services. Further, it explores controls and operational strategies that can facilitate energy storage to reach its full potential given state and federal regulatory rules.

Future State Lead: Suma Jothibasu, *sjothibasu@epri.com*

GAPS

Utility planning processes and tools: Utility planners need to better understand the potential economics of multi-use applications to support the development of processes and tools that incorporate generation, transmission, distribution, and customer planning. This requires listing use cases, identifying data needs, and creating models for different energy storage technology types.

Multi-stakeholder shared operations: Multi-stakeholder shared operations allows for multiple parties such as utilities, aggregators, and customers to control energy storage systems at different times, enabling multiple benefit streams. Developing reference cost-benefit analyses for use cases and ownership models and identifying data needs for shared monitoring and controls will support this type of operation.

Regulatory frameworks: Although energy storage can technically provide multiple services, some regulatory rules limit energy storage market program participation (for example, providing both reliability and non-reliability services). Informing regulators on the technical value of energy storage can help the rulemaking process, such as sharing multi-perspective cost-benefit evaluation techniques and novel business and ownership models. Regulations and standards are constantly changing, which need be consistently and regularly monitored.

Warranties and performance guarantees: Multi-use applications introduce challenges with warranties and performance guarantees of energy storage systems because the duty cycles may vary widely and change over the project life.

Operational decision making: To make informed decisions during energy storage operations, stakeholders across the energy storage value chain require algorithms, telemetry, communications, and information exchange that enables energy storage systems to attain optimal value for grid services—especially multi-use applications.

DER-VET™ is a free, open-source tool for calculating and optimizing energy storage value: www.der-vet.com

Bridges gaps in energy storage project development

A common communication tool

Evaluates customer and grid operation perspectives

CURRENT RESEARCH PRIORITIES

Tools to analyze multi-use applications: EPRI has several planning and analysis tools such as StorageVET® and DER-VET™ (valuation estimation tool), Customer Energy Storage Economics tool (customer specific), Production Cost Model, REGEN (transmission grid planning), DRIVE, and ADAPT (distribution grid planning). Each of the tools addresses unique aspects of energy storage analysis at different sectors. The goal is to continuously improve the tools independently and have them interface to answer common energy storage–related questions.

Framework for service identification and prioritization: EPRI has developed a process for identifying and prioritizing energy storage services and is applying and augmenting it. This method is designed to prioritize the primary and secondary energy storage services for a project. It also assists in determining what available energy storage technology types and products can provide the identified multiple services. This is a planning decision approach to screen for multi-use applications.

Tracking regulatory framework: Because the regulatory framework is constantly changing, the goal is to track and monitor the changes happening across various states, focusing on market services and customer-specific regulatory changes.

Energy storage control systems for multi-use applications: This research aims to define common inverter functions and communication protocols, facilitate system integration, and define methods for testing and validation. Defining fundamental algorithms for energy storage operations, such as SOC and SOH management, will improve the transparency, integration, and performance evaluation of the practical value from commercially available controllers for energy storage operational decision making specifically for multi-use applications. The result is a planned compilation and analysis of different architectures and functions of energy storage operational decision-making systems found in real-world projects.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
Energy Storage Analysis Case Studies *	Online resource repository of reference case studies using DER-VET. It provides valuation results and compares the evolution of quantifiable and monetizable value of energy storage for various services.
Customer Energy Storage Economics Tool (CESET) v1.0	Tool for the analysis of economic and use-case viability of customer energy storage systems based on installation size, site requirements, and utility rates.
Participation Options and Designs for Emerging Technologies in Electricity Markets: 2021 Update on Storage, Hybrid Storage, and DER Aggregations	This report tracks recent changes in electricity market designs to enable energy storage, hybrid storage, and DER aggregates to provide single and multi-use for customers and the wholesale market services that they can.
Customer Energy Storage Economics, Resiliency, and Customer-Utility Programs	Summary of customer utility programs across various states in the U.S. with case studies on the economics of shared value for utilities and customers using customer-sited storage and solar assets.

* Free to Public

FUTURE RESEARCH PLANS

Monetization of multi-use applications of energy storage: Using novel frameworks and tools, EPRI plans to explore the complexities of the monetization of multi-use grid and customer services with an energy storage system coupled with business models and regulatory structures required to accrue the optimal value to multiple stakeholders.

Tracking energy storage product warranties and performance guarantees: Technology and product providers' warranties and performance guarantees will be monitored to inform the industry on areas of improvement

TOTAL COST OF OWNERSHIP REDUCED

Energy storage technology costs have rapidly decreased over the last decade, yet there is still opportunity to further reduce costs throughout the project life cycle. In this future state, costs are minimized through improved energy storage technologies and products, reduced implementation and soft costs, and financing and insurance tools.

Future State Lead: Morgan Smith, *mdsmith@epri.com*

GAPS

Design optimization: Additional real-world data and modeling are needed on the underlying storage technology performance characteristics to support optimal sizing and design of balance of system. Field deployment experience is needed to quantify cost differences in design approaches. Practical considerations need to balance with evolving codes and standards. Lower soft costs can be achieved by standardizing leading design practices.

Project deployment practices: Energy storage deployment is still nascent and can benefit from best practices from other industries, such as petrochemical. Energy storage suppliers/integrators need to become more familiar with utility practices and processes, and installers need to become better at safely installing energy storage systems. Sharing lessons learned and experiences will help develop leading deployment practices.

Interconnection and permitting processes: The soft costs and timelines associated with interconnection and permitting can vary significantly based on the experience of the authority having jurisdiction (AHJ). This gap will become minimized as utilities, system operators, and AHJ have clear processes in place for integrating energy storage systems.

Energy storage maintenance practices: Maintenance costs, such as augmentation, can make up a significant portion of the overall life cycle cost. In addition, the energy storage ecosystem is still maturing and there are a limited number of qualified technicians. Spare parts availability is also an issue.

Risk and insurance accessibility: To support broad storage deployment, the industry needs to develop cost-effective strategies for mitigating safety and performance risks. Data analysis and stakeholder education are needed for utilities and other energy storage owners to make informed decisions on warranties, guarantees, and insurance options.

End-of-life (EOL) costs: A full life cycle cost analysis should include EOL costs. Currently, these costs are not well-understood because few commercially deployed systems have been decommissioned and the recycling infrastructure for lithium ion batteries is still limited. Documenting costs and identifying their drivers will inform stakeholders of the system life costs from manufacturing to EOL decision making, recycling, and disposal.

CURRENT RESEARCH PRIORITIES

Developing tools and guide for least cost storage deployment: EPRI's Energy Storage Integration Council is an open, technical collaboration of industry stakeholders that creates publicly available resources to support storage deployment. Current activities supporting cost reduction include solar-plus-storage acceptance testing, data specification, and cyber security requirements.

Gathering best practices: EPRI facilitates sharing project experiences, lessons learned, costs, and leading practices through the DER and Energy Storage Forum, advisory meetings, lessons learned databases, Integrated Grid Demonstrations member webcasts, and technical conferences.

Tracking costs to target cost reductions: Life cycle costs—including installation, operations, and end-of-life costs—are gathered. Research has included reviews of lithium ion cost projections, solar plus storage, flow batteries, and various emerging electrochemical batteries.

Documenting design practices: Best practices from demonstrations are being documented, including an understanding of project costs. EPRI is also developing a customer storage handbook for commissioning and interconnection.

Distribution and transmission energy storage projects and practices guides: These guides compile the best practices for project managers and distribution planners to provide guidance at various stages of the project life cycle for distribution and transmission connected energy storage systems. These guides aim to address a variety of topics, including safe design and operation and options for decommissioning and disposal at least cost.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
ESIC Energy Storage Implementation Guide*	A practical reference guide to the key considerations throughout the life cycle of an energy storage project. It references ESIC's 15 other tools/guides as well as other publicly available resources to support project deployment and includes over 100 lessons learned submitted by various industry stakeholders.
Customer Energy Storage Commissioning Guidebook: Residential and Small Commercial	A step-by-step checklist of several tried and tested best-practice procedures and recommendations for in-field verification of proper operation and monitoring of energy storage systems. This handbook builds from the 2020 guide.
Energy Storage System Taxonomy of Operating Behaviors: 1st Edition	A white paper that provides an initial classification system and unified terminology that utilities, storage owners, and developers can reference.
Energy Storage Functions Taxonomy Working Group*	This public group will be tasked with developing a consensus-based classification system and unified terminology describing the modes of behavior for energy storage and PV-plus-storage systems.
Transmission and Distribution Connected Energy Storage – 2021 Update: Projects, Products, and Applications	A report summarizing technology and deployment trends specific to utility distribution and transmission applications. It also features lessons learned through case study evaluations.

*Free to Public

FUTURE RESEARCH PLANS

Data-informed practices: Data gathered through EPRI's Performance and Reliability Initiative and other projects will inform energy storage system design and operation and maintenance practices to reduce life cycle costs.

Adapting general guidelines to utility-specific processes: As guides and handbooks are developed based on industry leading practices, EPRI will work with members to adapt these to fit within specific organizational processes.

REDUCING EMISSIONS WITH ENERGY STORAGE APPLICATIONS

High renewables penetration, electric vehicle use, delivered electricity efficiency, reduced emissions from the existing fossil generation fleet, and ecosystem protection are supported and provide operations flexibility through energy storage use and adoption.

Future State Lead: Giovanni Damato, *gdamato@epri.com*

GAPS

Energy storage studies on emissions impacts: Energy storage is not inherently clean. The emissions intensity of the resources that charge energy storage and are displaced by energy storage discharge and the applications and locations of deployment are critical to understand the impacts of energy storage on emissions. A clear framework for analyzing the impact of energy storage emissions is necessary along with the identification and categorization of use cases.

High renewable scenarios: There is a general understanding that the value of energy storage increases under conditions with higher renewables deployment and deeper decarbonization. However, analysis on potential drivers and impacts of energy storage to reduce emissions is limited. More analysis to understand technological, market, and policy conditions under which energy storage technologies could be deployed to reduce emissions for high renewable scenarios is required.

Long-duration storage applications: Currently, studies quantifying the change in environmental and economic impacts when long-duration energy storage is deployed are limited. Modeling enhancements to incorporate long-duration energy storage characteristics into long-term capacity planning models is necessary as well as the development of scenarios to model.

Metering and emissions accounting: Tracking the emissions intensity of the charging energy as well as the displaced emissions intensity of the marginal resource(s) through the continuous dispatch of energy storage is challenging. Current planning tools may not adequately capture emissions reductions for informed decision making for the deployment of energy storage. Furthermore, real-time operations and metering capabilities do not exist to account for complex energy storage dispatch, such as multi-use applications.

Emissions cost and value streams: Energy storage is one of many methods to support grid reliability, flexibility, and renewable integration. An integrated approach to system planning and decision making that can optimize on various metrics such as cost, multiple energy/capacity applications, efficiency, and other grid services to support renewables is necessary to properly evaluate energy storage.

CURRENT RESEARCH PRIORITIES

Incorporating environmental factors in energy storage project design and operation analysis: EPRI is working to implement appropriate emissions algorithms into the DER-VET™ tool.

Long-duration energy storage performance: EPRI's REGEN modeling tool is providing the understanding of longer duration energy storage systems' ability to provide improved emissions reductions and economic efficiencies.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
Long-Duration Energy Storage Benefits	Evaluation across a range of decarbonization strategies, technology, and cost sensitivities to understand the conditions under which certain energy storage technologies are economically deployed and the value of specific technologies for facilitating power sector decarbonization.
Energy Storage in Long-Term System Models: a Review of Considerations, Best Practices, and Research Needs*	A review that demonstrates the importance of capturing how the values of energy storage change in long-term models as the system composition changes.
Environmental Aspects of Fueled Distributed Generation and Energy Storage (P197) Updates and News, May 2021	This report discusses per- and polyfluoroalkyl substances (PFAS) in lithium ion batteries.
2021 Beyond 80% Analysis: Technological Options and Uncertainties for Net-Zero Electric Sector CO2 Emissions	Analysis using EPRI's U.S. Economy, Greenhouse Gas, and Energy (US-REGEN) model to evaluate how assumptions about policy, markets, and technologies affect net-zero pathways.
Overview of Emissions Impacts from Grid-Connected Battery Energy Storage	Issue Brief discussing GHG estimating impacts resulting from battery energy storage deployments and operational scenarios, including the emission impacts of grid-connected energy storage operated by utilities as well as those behind-the-meter at residential, commercial, or industrial sites.

* Free to Public

FUTURE RESEARCH PLANS

Continuation of the long-duration energy storage benefits study: EPRI plans to continue the foundational work of the Long-Duration Energy Storage Benefits study completed in 2021 that will include updated cost and performance data with more detailed characterizations in the modeling, additional scenarios, and more sensitivities.

Model development: EPRI will develop emissions models and create decision support tools from simple ones such as flowcharts to complex ones including optimization models that include emissions metrics.

SUSTAINABLE AND EQUITABLE LIFE CYCLE IMPLEMENTED

As energy storage technologies scale, it is increasingly important to develop business, operation and management practices that consider resource needs, environmental and social impacts, impacts to communities, and options to improve sustainability of materials, equipment, and facilities across their entire life cycle. In this future state, materials selection, extraction and processing, manufacturing, transportation, use and decommissioning practices, as well as consideration of environmental justice and energy equity impacts, maximize positive impacts to environment and society.

Future State Lead: Stephanie Shaw, *sshaw@epri.com*

GAPS

High social and environmental impact materials: Selected lithium ion battery materials have undesired environmental and/or social impacts. As a result, manufacturers are developing other technologies with reduced amounts of these materials, replacing higher impact materials with those of lower impacts (for example, cobalt-free modules) or working on non-lithium energy storage technologies. Information on the availability, effectiveness, cost, and environmental and social impacts of novel designs is needed by all stakeholders.

Life cycle assessment (LCA) data: Life cycle assessments of varying supply chain, energy storage design and implementation, operation, and end-of-life management scenarios can inform cost and social/environmental impacts of future choices. However, the accuracy and utility of these assessments rely on the quality of data that go into the calculations—and the data can be proprietary and difficult to obtain. Vendors, researchers, agencies, and policymakers should develop an organized collaborative process that is anonymized and aggregated to protect proprietary information while informing future industry development.

Procurement decision-making criteria: Electric utilities, energy providers, and other energy storage owners desire to make informed decisions about sustainability considerations but lack guidance on how to do so. Identification of metrics of merit, interviews with manufacturers and developers about their practices, quantitative assessments, practical examples, and case studies are needed. In turn, the needs of energy storage customers should be summarized and used to inform manufacturers and developers about desired characteristics relevant to sustainability assessments.

Global material supply adequacy, diversity, and resilience: Supply chain adequacy, diversity, and resilience are crucial to supporting a viable energy storage industry. Exploration and development of opportunities for domestic critical material supply and refinement and an understanding of the potential role of recycled materials in meeting overall demand of lithium, cobalt, nickel, and other critical materials are key needs. LCA of varying scenarios can inform potential cost and social/environmental impacts of supply chain choices and assist in providing actionable guidance.

Material certifications and traceability throughout life cycle: Some required and voluntary guidelines and certifications exist for documenting environmentally and socially relevant practices for sourcing of raw materials; others are being developed or considered. Current and developing metrics should be periodically reviewed, the outcomes comparatively analyzed, and recommendations made for their use in decision-making processes across the energy storage life cycle.

CURRENT RESEARCH PRIORITIES

Evaluating supply chain practices and resource availability: Supply chain diversity and resilience are crucial to facilitate new deployments in both stationary and vehicle platforms. EPRI is tracking resource availability of critical materials on a global scale and evaluating the increasing number of efforts to develop U.S. domestic supplies through new resource extraction and recycling of battery modules. Environmental and social metrics associated with material supply chains are reviewed and tracked along with voluntary practices, certifications, and corporate policies that help differentiate sources of materials and actors throughout the supply chain. EPRI evaluates how these can be used by electric utilities as part of their decision-making processes.

Evaluating alternatives to high-impact materials: Novel energy storage system compositions are under active development. EPRI performs and tracks emerging research and insights on the performance of these novel materials and their impacts. Upcoming is a report summarizing elements of sustainable battery design that are in development and moving toward commercialization. This topic is also assessed through the Emerging Technology supplemental project demonstrations that are testing and evaluating novel cobalt-free, low-cobalt, and non-lithium battery technologies. Current knowledge on trade-offs, if any, between material impacts (for example, supply issues, recycling efficiency) and performance (degradation, cycle life), safety, or cost are reviewed and evaluated.

Document circular economy principles: Implementing sustainable end-of-life management touches equipment and facility procurement practices, operations and maintenance protocols, life extension practices, asset recovery plans, environmental compliance, and sustainability management. An Interest Group on Circular Economies for Clean Energy Technologies has been launched, for which EPRI is actively seeking members to discuss how electric power companies can integrate their energy storage system fleet activities with practical circular and sustainability principles.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
Sustainability Aspects of the Lithium Ion Battery Supply Chain*	Survey of major trends summary of recent work on these topics, covering efforts by researchers, policy experts, manufacturers, and industry organizations to address key materials adequacy, environmental impacts, and human rights issues involved in producing lithium ion batteries.
Environmental Aspects of Utility-Scale Energy Storage Systems: An Environmental, Health and Safety Comparison Across Commercially-Available Technologies	Qualitative impact ratings for lithium ion batteries, flow batteries, sodium sulfur batteries, flywheels, compressed air energy storage, and pumped hydrological storage over a range of health, safety, and environmental metrics for use as an educational and road mapping tool.
Approaches for Evaluating Potential Human Health Consequences of Utility-Scale Lithium ion Battery Failures	Report introducing concepts that can be used to develop a framework for evaluating potential human health risks associated with lithium ion battery failures. The report relies heavily on a quantitative risk assessment (QRA) methodology that is used to assess industrial accidents, mainly outside the United States, while also taking more U.S.-centric risk assessment approaches and principles into account.
Life Cycle Assessment of Lithium Ion Batteries for Grid-Scale Storage	This Technology Innovation technical update considers a variety of realistic scenarios for battery energy storage system designs, applications, and end-of-life management, based on real-world procurement specifications, dispatch profiles determined by EPRI's StorageVET tool, and modeled battery degradation.
Operationalizing Circular Economy Principles for Renewables and Batteries: Electric Power Company Practices*	Documents tangible ways in which electric power companies are proactively operationalizing circular economy principles in their business practices.

*Free to Public

FUTURE RESEARCH PLANS

Environmental, health, and safety review beyond lithium technologies: EPRI plans to track resource supply and associated environmental, health, safety, and social impacts, of an expanded range of storage technologies such as solid-state lithium, liquid metal, or thermal storage.

Inform procurement: Environmental and sustainability metrics and certifications that have potential to inform battery energy storage system owners and drive future manufacturer and developer actions will be summarized. Practical examples and case studies of how metrics are being used by peers at procurement as well as through the storage system life cycle will be summarized.

Environmental justice and energy equity: Opportunity assessment for enhancement of equity and justice metrics through facility design, siting, operations and decommissioning.

END-OF-LIFE IMPACTS MINIMIZED

End-of-life management options for battery modules and other energy storage system components are limited and expensive. Battery production is rapidly increasing, both for electric grid deployments and electric vehicles, and a solid and standard method to manage their end-of life process is needed. This future state envisions safe and economic disposal, recycling, and reuse of energy storage system components, which will also mitigate negative environmental end-of-life impacts.

Future State Lead: Stephanie Shaw, *sshaw@epri.com*

GAPS

Safe and responsible recycling and disposal: Currently there is limited guidance regarding protocols that ensure safe handling of battery modules during removal, trucking, recycling, and/or disposal. These protocols must be developed, circulated, and standardized. In addition, the environmental and human health impacts of recycling, reuse, and disposal need to be evaluated, minimized, and continually assessed so new information can be shared with stakeholders in the energy storage ecosystem and especially as new and novel battery technologies are commercialized.

End-of-life utility planning and contracts: When sourcing an energy storage system, all aspects need to be planned for, including end of life. Procurement processes and requests for proposals do not always include end-of life plans, which can lead to unexpected financial, compliance, or logistical issues. Development of effective strategies to be implemented at the point of design and contractual development is key, which could include creating decommissioning plans, assigning responsibility, developing financial sureties—including of decommissioning costs in project life cycle costs—and considering evolving regulatory requirements.

Economic recycling processes for lithium ion batteries: Cost-effective and efficient collection and recycling processes must be developed for the wide range of battery chemistries, stoichiometries, and form factors that are in use as well as those in development. Because few commercially deployed stationary energy storage systems and electric vehicle modules have been decommissioned, recycling infrastructure for large-format lithium ion batteries is still limited and needs to be addressed. Documentation of key cost drivers is needed to inform stakeholders across the energy storage life cycle.

Validated battery second-life products and applications: Improved understanding of the feasibility of second-life or reuse products and applications remains a large gap in end-of-life management options. Data analysis and stakeholder education on the performance, cost, certification, and environmental impacts of electric vehicle batteries reused in stationary energy storage applications are needed for utilities and other owners, manufacturers, and developers to make informed decisions.

Regulatory approach for recycling and materials recovery: A patchwork of regulatory and policy actions is being developed globally by authorities having jurisdiction at federal, state, and/or local levels to encourage or require recycling and reuse of battery modules. Approaches include fees at purchase, extended producer responsibility, manufacturer takeback, and labeling. However, these are inconsistent in scope and method and, if not thoroughly considered, could result in unintended consequences.

Removal of packed battery system components for recycling and disposal

CURRENT RESEARCH PRIORITIES

Developing guidelines. EPRI provides guidance on financial and logistical expectations of decommissioning and end-of-life management practices to support battery energy storage system owners. EPRI also reviews and informs regulatory and policy development processes on recycling and materials recovery.

Gathering best practices: EPRI facilitates sharing project experiences, lessons learned, and leading practices through documenting case studies of battery disposition, summarizing decommissioning plans, interviewing end-of-life vendors, and participating in peer discussions and stakeholder presentations.

Evaluating recycling innovations: EPRI tracks and evaluates ongoing recycling R&D efforts that include improving recycling processes for higher recovery efficiencies, extracting higher grade product purities, and lowering embedded manufacturing losses and energy use. These activities are expected to further increase in future years because many countries are enhancing the development of domestic value chains for lithium ion batteries and other energy storage technologies.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
End-of-Life Management for Lithium Ion Battery Technologies: Issues, Uncertainties, and Opportunities	Landscape report summarizing issues, uncertainties, and opportunities for large format lithium ion battery recycling, reuse, and disposal.
Recycling and Disposal of Battery-Based Grid Energy Storage Systems: A Preliminary Investigation*	Estimates the cost of recycling and disposal for a model battery energy storage system framework.
Guidelines for Assessing End-of-Life Management Options for Renewable and Battery Energy Storage Technologies*	Lessons learned from the battery facility decommissioning process as shared by electric utilities. Suggestions for actions to be taken at the point of procurement to proactively prepare for end-of-life management.
Lithium Ion Battery Energy Storage Systems End-of-Life Management Infographic*	Succinctly and graphically summarizes key metrics for end-of-life management, such as deployment and waste volume projections by chemistry, composition of facility balance-of-system composition and module composition, and decommissioning costs.
Battery Energy Storage System Recycling and Disposal Investigation*	Updates cost estimates related to decommissioning for current facility designs and service options.

* Free to Public

FUTURE RESEARCH PLANS

Data-informed cost estimates: Data gathered from electric utilities and other energy storage owner/operators inform updates to decommissioning, recycling, and disposal cost estimates, which will also be expanded beyond lithium ion batteries to a wider range of battery and energy storage technologies.

Review and assess second-life or reuse feasibility: Reuse, or second life, applications remain in an early stage of development and demonstration. Performance, safety, cost, certification, and environmental impact aspects of the reuse of electric vehicle battery modules in stationary energy storage configurations will be assessed for suitability to utility-specific applications and needs. EPRI is participating in second-life battery demonstration projects funded by California Energy Commission and in working groups considering ways to assess the recyclability or reuse potential of battery modules.

TECHNOLOGY ADVANCEMENTS ACCELERATED

New technologies under development today may offer enhanced performance in cost, durability, safety, environmental, and other attributes that expand deployment and applicable use cases in the future. These technologies, if effectively demonstrated and integrated, may offer greater power system and public benefits. In this future state, known gaps in current energy storage technologies are addressed and a process is in place for technology advancement to facilitate faster and more effective commercial emergence.

Future State Lead: Lakshmi Srinivasan, *lsrinivasan@epri.com*

GAPS

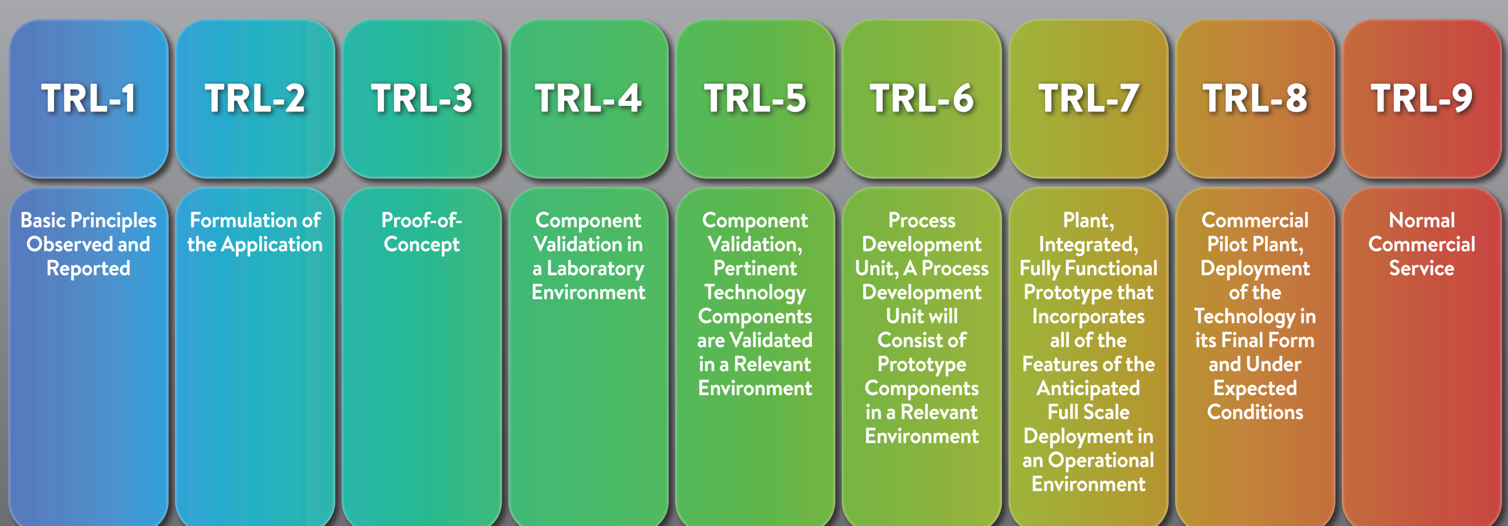
Technology development and validation timelines: New technologies are under development, but the time required to demonstrate and validate technologies can take years. Current demonstration programs are piecemeal, and it is difficult to obtain testing data sets to facilitate technology advancement. There is a lack of standardized demonstration processes, which impedes energy storage technology advancements.

Funding gaps for intermediate technology readiness levels: New energy storage technologies typically find funding at early technology readiness levels (TRLs) to develop core intellectual property and at late TRLs to get to commercial opportunities. However, expensive and time-consuming work is needed in the intermediate TRLs to demonstrate, iterate, and optimize technology for commercial products. Although mid-TRL development work is important to build critical knowhow and end-user technology familiarity, sustained funding can be difficult to obtain.

Cross-disciplinary coordination: Effective development and evaluation of new energy storage options requires exceptional cross-disciplinary knowledge sharing and coordination. The various disciplines that need to be engaged in the energy storage technology development process include scientists, engineers, manufacturers, business and marketing experts, policy makers, legal, and supply chain. Institutions require more than deep technical knowledge—they require broad energy storge knowledge of how it impacts the entire ecosystem.

Technology goals and performance targets: Clear technical and economic targets for energy storage use cases to support present and future grid needs are needed to guide energy storage product and project developers. Industry needs to understand and optimize trade-offs between cost, performance, and durability.

TECHNOLOGY READINESS LEVEL



CURRENT RESEARCH PRIORITIES

Energy storage technology tracking and evaluation: EPRI maintains the Energy Storage Technology Database to track and evaluate technology readiness levels, performance characteristics, and demonstration status to inform end users of the current state of technology landscape and identify technologies for testing and deployment.

Emerging technology demonstrations: Evaluation of the technology readiness of pre-commercial and long-duration energy storage technologies with testing, demonstration, and data analysis of new energy storage technology projects, leveraging advanced data infrastructure and methods through the Emerging Energy Storage Technology Testing and Demonstration supplemental project.

Customer energy storage system testing: EPRI manages pilot projects to support planning, develop control and communication architectures, and assist with specifications prior to system implementations. EPRI also assists in developing test plans to guide operations during the demonstration phase and assessment of operational performance. EPRI has also reviewed utility and third-party programs that provide incentives encouraging the adoption of customer-sited storage.

Host collaborative knowledge sharing events: The Energy Storage Integration Council (ESIC) facilitates cross-functional knowledge sharing and accelerates development of common reference guidelines, such as the ESIC Energy Storage Test Manual and ESIC Energy Storage Technical Specification Template to improve standardization of evaluation methods and terminology. These tools are constantly being revised with industry input and are adapted for use with emerging technologies.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
Energy Storage Technology Database Report: 2021 - Annual Year-End Snapshot Report and Database Access	Web-based database of energy storage technologies with technology process description, performance and cost attributes, benefits and challenges, and technology readiness.
Bulk Energy Storage Costs and Performance	Techno-economic analyses for several bulk storage technologies, examining commercial-scale systems.
Lithium ion Battery Advancements for Electric Vehicle and Stationary Storage Applications	Overview of the latest advancements in lithium ion technology, including improvements in performance, packaging, and balance of system.
ESIC Energy Storage Test Manual*	Test protocols to support performance and functional evaluation of storage technologies with a consistent methodology.
Customer-Sited Energy Storage Programs	This report reviews utility and third-party programs that provide incentives encouraging the adoption of customer-sited storage. Although these programs encourage adoption of storage via incentives, many of these programs also encourage or require utility and third-party aggregated dispatch of these systems.

* Free to Public

FUTURE RESEARCH PLANS

Adapt general guidelines to utility-specific processes: As guides and handbooks are developed based on industry leading practices, EPRI will work with members to adapt these to fit their utility-specific organizational processes, resulting in accelerating energy storage system deployment.

Innovation workshops: Develop innovation workshops to educate and enable knowledge exchange between utility departments, vendors, project developers, regulators, and other stakeholders. Topics will include safety and emergency response best practice, technology capabilities, supply chain and logistics constraints, among others.

FUTURE WORKFORCE AVAILABLE AND TRAINED

The industries responsible for energy storage planning, deployment, and use have access to skilled workforce and development programs. In this future state, there is an available workforce to fill critical roles such as planners, operators, construction and maintenance personnel, scientists, system integrators, first responders, and policymakers.

Future State Lead: Erin Minear, *eminear@epri.com*

GAPS

Workforce growth training materials and tools: Energy storage has unique technology and operating characteristics. For the existing workforce to gain the competencies to adequately assess and deploy energy storage, new tools and training materials need to be developed. Steps to address this gap include identifying workforce gaps and future needs, mapping competencies to roles, determining what existing resources can be leveraged, and prioritizing efforts to develop new materials.

Project life cycle management: There are several new stakeholders that should be engaged throughout the life of the project. For example, utilities will need to develop organizational processes and programs to ensure that the right people are engaged at the right time and have the necessary information for their role.

Policymaker education: Policymakers require an understanding of the evolving grid needs and how energy storage can help address those needs now and in the future to support the development of energy storage–specific policy as well as clean energy policy. Technical topics being addressed through policy include dual-use energy storage to serve distribution or transmission and market services, needs for long-duration storage, reliability and environmental reporting, hybrid system market participation, and end-of-life battery management.

Emergency preparedness: Emergency plans and associated training should be established with clear delineation of responsibilities to mitigate risk through the siting, construction, operation, and decommissioning phases of a project. In addition, the specification and design of the system will impact the ability of emergency responders to adequately address the situation and make informed decisions.

CURRENT RESEARCH PRIORITIES

Provide fundamental energy storage educational materials: "Energy Storage 101" educational materials get new stakeholders up to speed on storage uses, technology, and implementation. Materials are continuously refreshed and presented through several channels, including web-based materials, online and in-person courses, and computer-based training modules.

Support utility knowledge and program development: EPRI provides energy storage workshops to utilities to train their employees and inform them on technical, economic, market, regulatory, and policy issues as well as energy storage technologies, product definition, technical and economic analysis, and grid deployment issues applicable to the utility's service territory. Assistance is also provided on energy storage analysis, deployments, and program development with customization of tools and how to apply them to specific projects and to develop standardized processes.

Identify workforce gaps: Through ESIC, technical forums, utility member discussions, and interviews with industry stakeholders, EPRI identifies gaps in workforce development to define future research priorities. In the Fire Prevention and Mitigation project, EPRI brings together stakeholders to discuss energy storage deployment experiences and how to interact with first responders and other organizations to develop new training.

Share planning tools: EPRI has developed tools, such as DER-VET and the Lithium Ion Battery Storage Ongoing Cost Study and Estimating Tool, that planners can learn to use to assess storage cost, value, and grid benefits over the life of the system. The tools also provide an understanding of how various technology characteristics impact cost-benefit assessments to make informed decisions about technology selection, sizing, and timing.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
StorageWiki.epri.com*	EPRI's Energy Storage Program hub to online resources. This wiki includes publicly accessible "Energy Storage 101" content.
Introduction to Energy Storage Short Courses	Introductory courses on energy storage and deep dives in safety, technology, and valuation provided through EPRI's GridEd Center for Grid Engineering Education program.
DER and Energy Storage Forum	An online forum connecting members to EPRI staff and their peers at other utilities. Members can post questions or search the database of previous forum discussion to gain insights on costs, implementation strategies, and other practices.
Worker and First Responder Safety Concerns Related to Battery Energy Storage Facilities: A Review of the Literature and Interviews with Local Fire Departments	Paper that reviews and identifies the gaps in the current knowledge base of worker and first responder safety concerns and practices at utility-scale BESS facilities.

* Free to public

FUTURE RESEARCH PLANS

Tailored training and educational materials: To maximize the impact of training and educational materials, resources will be tailored to specific stakeholders and new material added to support their responsibilities.

Promoting adoption of standard practices: EPRI will continue to promote the use and adoption of ESIC guides and tools so new stakeholders can leverage industry-vetted practices.

CROSS-INDUSTRY BREAKTHROUGHS TRACKED AND INTEGRATED

Energy storage can be advanced by adopting and adapting breakthroughs from other industries. In this future state, cross-industry activities influence energy storage system deployment and use through monitoring and understanding how other industries have developed.

Future State Lead: Peggy Ip, *pip@epri.com*

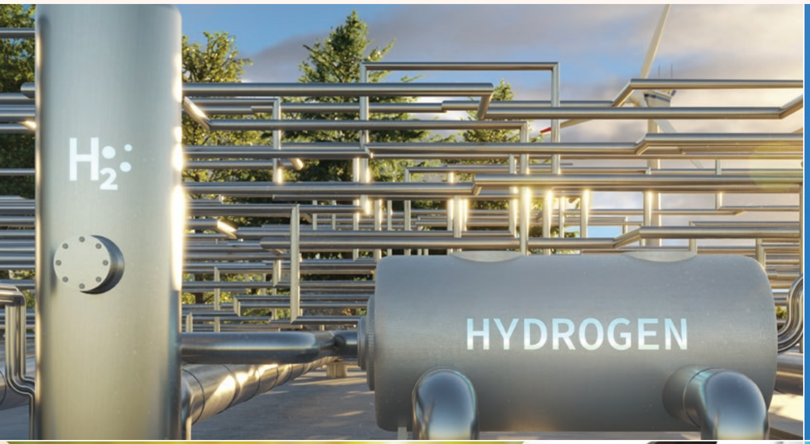
GAPS

Assessments of disruptive technologies and their maturity: Ongoing research and development in advanced battery technologies, material science, power electronics, artificial intelligence, forecasting, and other industries may impact trajectories in the energy storage industry. Knowledge can be gained by assessing these disruptive technologies and how they developed, harnessing them in the context of energy storage deployment.

Collaboration and knowledge sharing among utility subject matter experts: As more energy storage systems are deployed, the industry and subject matter experts gain invaluable experience throughout the integration processes—but this information is not transparent. There is a need to share best practices and lessons learned and standardize implementation processes to enhance awareness and knowledge within the energy storage industry and across other industries.

Collaboration among utility subject matter experts: As more energy storage systems are deployed, the industry and subject matter experts gain invaluable experience throughout the integration processes. Collaborating among utility experts, sharing best practices and lessons learned, and standardizing implementation processes can socialize awareness and knowledge within the energy storage industry and across other industries.

Benchmarking other industry best practices and processes: The electric grid is undergoing transformation in many ways: modernization, decentralization, digitization, and decarbonization. It is important to benchmark other industry best practices and processes to leverage for the energy storage industry to facilitate progress. Industries such as transportation, hydrogen storage, telecommunications, cyber security, renewable generation, and building modernization with connected devices may have best practices and lessons learned to draw from.



CURRENT RESEARCH PRIORITIES

Monitor and support demonstration of new, pre-commercial technology solutions: EPRI's Incubatenergy® Network is made up of leading clean energy accelerators globally that support more than 1,000 early-stage companies working in clean energy, transportation, built environment, precision agriculture, artificial intelligence, and other electrification-focused sectors. Through Incubatenergy, EPRI facilitates engagements with innovative and breakthrough startups collaborating with utilities and other industry stakeholders. EPRI is active in "vehicle to other" (V2X) demonstrations and understanding how V2X technologies compete with stationary batteries. In addition, it is important to understand how adoption of electric transportation impacts supply chain dynamics for stationary batteries, including second-use applications.

Centralize and analyze energy storage data, leveraging artificial intelligence and machine learning: In its second phase, the Energy Storage Performance and Reliability Foresight Project is a data initiative that aims to centralize energy storage operation data and enable advanced algorithms and analytics for deeper understanding of energy storage operation. This effort leverages EPRI's Data Platform to enable more secure and interactive display of results as well as comparison of systems of different battery chemistries, configurations, and duty cycles. In this same effort, EPRI is collaborating with national labs to develop and train predictive modeling to project future performance based on historical operation data.

Tracking low-carbon alternatives: Through EPRI's Low-Carbon Research Initiative (LCRI), hydrogen and other low-carbon generation technologies and alternative energy carriers are being tracked. Understanding potential adoption of low-carbon alternatives will provide insight into how storage might be deployed in the future.

FEATURED RESOURCES

DELIVERABLE	DESCRIPTION
EPRI EV Infrastructure Working Council *	EPRI established the National Electric Transportation Infrastructure Working Council (IWC), which meets regularly to advance the adoption of fleet electric transportation by addressing technical issues associated with resiliency, interoperability, and development of utility/customer planning tools.
Electric Transportation Update, August 2021	This newsletter provides information on EPRI research, highlights member projects, and discusses other topics of interest in electric transportation.
AI Based Vulnerability Assessment for Power Distribution Systems Considering Distributed Energy Resources (DER)	This report examines the feasibility of a dynamic vulnerability assessment methodology that leverages deep learning to detect attack surfaces for distribution systems with high DER and smart devices penetration.
Overview of Alternative Low-Carbon Backup Generator Technologies	This report examines options for replacing diesel generators with alternative, lower carbon technologies and associated fuels to help reduce carbon emissions from the fleet, such as hydrogen, biogas, compressed natural gas (CNG), liquefied natural gas (LNG), liquefied petroleum gas (LPG), biomethane, NH3, and others.
Measurement and Verification for Distributed Energy Resources Providing Grid Services: New Complexities, Common Approaches, and Research Needs	This white paper provides a starting point for measurement and verification (M&V) practitioners tasked with understanding the new complexities introduced by wider participation of DER in delivering grid services.

* Free to Public

FUTURE RESEARCH PLANS

Data-driven disruptive techniques: EPRI's Energy Storage Performance and Reliability Foresight project will collect system operation data for a data analytics effort to deepen the industry's knowledge around operation, performance, degradation, maintenance practices, safety, and more. Understanding the long-term performance of energy storage systems is critical as electric grids become more dependent on this resource to allow for more flexibility while maintaining reliability.

Engagement with incubator, advanced technology programs, and funding opportunities: Incubatenergy Labs, managed by EPRI, facilitates new technology demonstrations every year that inspire creative new areas of research focus. EPRI partners with utilities and technology developers to respond to federal and state demonstration opportunities.

Leverage ongoing development in artificial intelligence and machine learning: EPRI continues to extract methodologies for using AI and ML in applications related to energy storage, including optimization in dispatch, DER-VET optimization, and potential work in forecasting market signals—including energy prices.

About EPRI

Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

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