

ENERGY STORAGE ROADMAP | VISION FOR 2025



INTRODUCTION

Energy storage is essential to a modern electric grid - it enables the grid to achieve ambitious renewable energy goals and enhances power system reliability and resilience.

This roadmap envisions a path to 2025 where energy storage enhances safe, reliable, affordable, and environmentally responsible electric power. This roadmap serves as a guide for EPRI's energy storage research activities, including industry and government research collaboration.



ROADMAP DEVELOPMENT PROCESS:

This energy storage collaborative roadmap development process consisted of these phases:



CURRENT STATE: WHERE IS ENERGY STORAGE TODAY?

Safety – Sporadic fire events, thermal runaway data and modeling gaps, and lagging standards and code development and adoption results in uncertainty.

Reliability – Operational project experience is small but growing and energy storage system performance is advancing.

Economics – Costs are decreasing, and operational value is better defined, but additional technical study is needed to inform policy.

Environmental – Potential to enable increased renewable energy use is understood, but issues in battery materials and recycling create uncertainty.

Innovation – Rapid technology acceleration is not fully captured due to gaps in education and experience.






DRIVERS: WHICH FORCES ARE SHAPING ENERGY STORAGE DEVELOPMENT AND USE?

- ➔ Technology advancements in storage density, controls, performance and integration improvements
- ➔ Electric service reliability and resilience needs caused by extreme weather events, grid modernization initiatives, and business continuity requirements
- ➔ Economic transformation with lower costs of energy storage, electric vehicles, and renewables coupled with expanding monetization opportunities for storage
- ➔ Environmental and social policy causes fossil generation retirements, renewables & storage mandates, and electrification initiatives
- ➔ Individual and organizational climate goals drive grass roots awareness and action



FUTURE STATES: ENERGY STORAGE FOR 2025

These target future states were collaboratively developed as visions for the beneficial use of energy storage.

|  |  |  |  |  |
|--|--|--|---|--|
| SAFETY | ELECTRICITY RELIABILITY | ECONOMICS | ENVIRONMENTAL RESPONSIBILITY | INNOVATION |
| Community resilience use cases viable | Energy storage asset reliability characterized and enhanced | Planning and operational modeling validated and applied | Reduced emissions with energy storage applications | Cross-industry disruption awareness and integration |
| Safety practices established | Energy storage controls integrated and interoperable | Multi-use applications enabled | Sustainable life cycle implemented | Future workforce available and trained |
| Asset hazards characterized and minimized | Planning and maintenance practices established | Project capital and soft costs reduced | End-of-life impacts minimized | Technology advancements accelerated |

FUTURE STATES AND GAPS

The future states are further described below, including the gaps to address which may enable this future vision for energy storage.



SAFETY

COMMUNITY RESILIENCE USE CASES VIABLE

Solutions are developed and demonstrated to support a range of customer and community resilience applications for disruptions and disasters.

Gaps:

- Quantification of resilience value for communities
- Energy storage public safety use definition
- Community and customer awareness of options
- Coordination of customer and utility assets

SAFETY PRACTICES ESTABLISHED

Codes, standards, and best practices for integration and operation of energy storage support the safety of all.

Gaps:

- Public safety guidelines
- Installation, transportation, and handling safety guidelines
- Operator guidelines
- Maintenance guidelines
- Incident response protocols
- Design and manufacturing safety practices

ASSET HAZARDS CHARACTERIZED AND MINIMIZED

Safety hazards are characterized and mitigated with informed and comprehensive approaches to reduce the probability and severity of safety events.

Gaps:

- Battery thermal runaway characterization and mitigation
- Siting risk management practices
- Emerging storage technology safety information and analysis
- Failure modes and effects analyses
- Fire hazard testing and models



ELECTRICITY RELIABILITY

ENERGY STORAGE ASSET RELIABILITY CHARACTERIZED AND ENHANCED

Robust operational data shared through standardized metrics and testing inform planning, operations, and maintenance decision making.

Gaps:

- Operational data availability
- Analysis and benchmarking of available technology data
- Reliability models for utility planners and operators
- O&M practices and asset management

ENERGY STORAGE CONTROLS INTEGRATED AND INTEROPERABLE

Energy storage control systems support multiple-use applications and interoperability with utility systems to support predictable, reliable, and flexible operations.

Gaps:

- Open standards for communications and controls
- O&M practices and asset management
- Cyber security, including firmware upgrade verification
- Business continuity

PLANNING AND MAINTENANCE PRACTICES ESTABLISHED

Calibrated models and best practices support power system planning and O&M practices to maximize predictability and optimize maintenance.

Gaps:

- Reliability and performance data, planning tools and methods
- Operational practices for degradation management
- Failure characterization and predictive maintenance
- Maintenance approach consistency



ECONOMICS

PLANNING AND OPERATIONAL MODELING VALIDATED AND APPLIED

Methods and models for valuation support robust and economically optimized project planning, operation, and integration into utility practices.

Gaps:

- Project operational case studies
- Benchmarked modeling software
- System and portfolio planning tools and methods
- Valuation of long-duration storage and hybrid systems such as solar-plus-storage

MULTI-USE APPLICATIONS ENABLED

Utilization and value streams are maximized through innovative business models, advanced controls, and financing.

Gaps:

- Utility planning processes and tools
- Multi-stakeholder shared operations
- Regulatory frameworks
- Warranties and performance guarantees
- Controls and optimization methods

PROJECT CAPITAL AND SOFT COSTS REDUCED

Project life cycle costs are minimized through improved energy storage technologies and products, reduced soft costs, and financing and insurance tools.

Gaps:

- Project design optimization
- Project deployment practices
- Interconnection and permitting processes
- Risk and insurance accessibility
- End-of-life options
- Ensured equipment supplies and service



ENVIRONMENTAL RESPONSIBILITY

REDUCING EMISSIONS WITH ENERGY STORAGE APPLICATIONS

High renewables adoption, electric vehicle use, delivered electricity efficiency, reduced emissions from existing fossil generation fleet, and ecosystem protection are supported.

Gaps:

- Documented use to reduce emissions
- High renewable scenarios
- Long-duration storage applications
- Metering and emissions accounting
- Emissions cost and value streams

SUSTAINABLE LIFE CYCLE IMPLEMENTED

Materials selection and extraction practices, manufacturing, transportation, and deployment practices consider and minimize negative impacts to environment and society.

Gaps:

- High social and environmental impact materials
- Life cycle assessment (LCA) data
- Procurement decision-making criteria
- Global supply chain diversity and resilience
- Materials certifications and traceability throughout life cycle
- Material supply adequacy

END-OF-LIFE IMPACTS MINIMIZED

Safe disposal, recycling, and reuse of energy storage system components minimize negative environmental impacts of energy storage projects at end of life.

Gaps:

- Safe and responsible recycling and disposal
- End-of-life utility planning and contracts
- Economic recycling processes for lithium ion batteries
- Validated battery second-life products and applications
- Regulatory support for recycling and materials recovery



INNOVATION

CROSS-INDUSTRY DISRUPTION AWARENESS AND INTEGRATION

Maintain awareness and strategic focus on broad industry disruptions that may shape or complement energy storage deployment and use.

Gaps:

- Assessments of disruptive technologies and tipping points
- Collaboration among utility subject matter experts
- Benchmarking other industry best practices and processes

FUTURE WORKFORCE AVAILABLE AND TRAINED

The industries responsible for energy storage have access to skilled workforce and development programs to address storage opportunities.

Gaps:

- Workforce growth tools and training materials
- Project life cycle management
- Policymaker education
- Emergency preparedness

TECHNOLOGY ADVANCEMENTS ACCELERATED

Known gaps in current technology state are addressed and technology advancement process is in place to facilitate faster and more effective commercial emergence and iteration.

Gaps:

- Technology development and validation timelines
- Funding gaps for intermediate technology readiness levels
- Cross-disciplinary coordination
- Technology goals and performance targets
- Technology demonstration pathways



DEVELOP RESEARCH ACTIVITIES

This roadmap will guide EPRI's research activities developed through annual research portfolios, supplemental demonstration projects, and collaboration activities with industry and public stakeholders. The roadmap will be augmented, revisited, and benchmarked periodically with input from EPRI's members and outside advisors.

ACKNOWLEDGMENTS:

EPRI would like to thank these members and advisors who have actively developed and reviewed this roadmap. Without their input, this roadmap would not be possible: Steve Baxley, Southern Company; Bill Muston, Oncor; Kincheiu Wei, Puget Sound Energy; Jigar Patel, Hydro One; Sharon Bonesteel, Salt River Project; Tom Butler, Tennessee Valley Authority; Vince Herda, Great River Energy, Jorge Araza, Southern California Edison; Tom Fenimore, Duke Energy.

EPRI TECHNICAL CONTACTS:

Ben Kaun

Program Manager, Energy Storage and Distributed Generation
bkaun@epri.com

Eva Gardow

Principal Technical Leader, Energy Storage and Distributed Generation
evgardow@epri.com

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI members represent 90% of the electricity generated and delivered in the United States with international participation extending to nearly 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; Dallas, Texas; Lenox, Mass.; and Washington, D.C.

Electric Power Research Institute

3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com