2024 Biennial Energy Storage Review

Electricity Advisory Committee Recommendations for the U.S. Department of Energy June 05, 2025

Introduction

This report fulfills the duties assigned to the Energy Storage (Technologies) Subcommittee (the Subcommittee) of the Electricity Advisory Committee (EAC) by the Energy Independence and Security Act (EISA) of 2007 related to assessing the U.S. Department of Energy's (DOE) activities in energy storage technologies. Title VI, Section 641(e) of EISA requires the formation of a Council to serve in an advisory role to DOE and the Subcommittee was formed in March 2008 to serve that function. Specifically, EISA Section 641(e)(4) states that every 5 years "the Council, in conjunction with the Secretary [of Energy], shall develop a 5-year plan for integrating basic and applied research so that the United States retains a globally competitive domestic energy storage industry for electric drive vehicles, stationary applications, and electricity transmission and distribution." EISA Section 641(e)(5) states further that "the Council shall (A) assess, every two years, the performance of the Department in meeting the goals of the plans developed under paragraph (4); and (B) make specific recommendations to the Secretary on programs or activities that should be established or terminated to meet those goals." This report serves the purpose defined in EISA Section 641(e)(5) and presents the Subcommittee's and EAC's findings and recommendations for DOE.

Background

In December 2020, DOE released the Energy Storage Grand Challenge (ESGC), which is a comprehensive program for accelerating the development, commercialization, and utilization of next-generation energy storage technologies and sustaining American global leadership in energy storage. While technology offices had established individual goals and targets in the past and had invested more than $1.6 billion into energy storage research and development (R&D) from fiscal years 2017 through 2020, the Department never had a comprehensive strategy for addressing energy storage.

The ESGC established top-line cost-based goals for energy storage systems in its Roadmap:

- $0.05/kWh levelized cost of storage for long-duration stationary applications, which is a 90% reduction from 2020 baseline costs by 2030. Achieving this levelized cost target would facilitate commercial viability for storage across a wide range of uses, including meeting load during periods of peak demand, grid preparation for fast charging of electric vehicles (EVs), and applications to ensure the reliability of critical infrastructures, including communications and information technology.

- $80/kWh manufactured cost for a battery pack by 2030 for a 300-mile-range EV, which is a 44% reduction from the current cost of $143/rated kWh. Achieving this cost target would lead to cost-competitive EVs. Advances in battery production for transportation applications are anticipated to continue benefiting the production, performance, and safety of similar technologies used in batteries for stationary applications.

DOE established a holistic approach to meeting the ESGC goals by establishing five tracks focusing on taking fundamental R&D for storage technologies all the way through to production and deployment. The five tracks are described below:

- The **Technology Development Track** aligns DOE's ongoing and future energy storage R&D around use cases and long-term leadership.

- The **Manufacturing and Supply Chain Track** will develop technologies, approaches, and strategies for U.S. manufacturing that support and strengthen U.S. leadership in innovation and continued at-scale manufacturing.

- The **Technology Transition Track** will work to ensure that DOE's R&D transitions to markets through field validation, demonstration projects, public-private partnerships, bankable business model development, and the dissemination of high-quality market data.

- The **Policy and Valuation Track** will provide data, tools, and analysis to support policy decisions and maximize the value of energy storage.

- The **Workforce Development Track** will educate the workforce, who can then research, develop, design, manufacture, and operate energy storage systems.

Furthermore, in the Technology Development Track, the ESGC identified, through engagement with stakeholders, central use cases that represent the current and future ambitions for the use of energy storage systems. The use cases, the drivers of those use cases, and the price targets for energy storage systems meeting those use cases are identified below.

USE CASE	DRIVERS	TARGET
Facilitating an Evolving Grid	Increasing the adoption of variable resources and dynamic changes in customer demand to ensure grid reliability/resilience	\$0.03–\$0.05/kWh levelized cost of storage
Serving Remote Communities	Electricity premium due to fuel logistics and maintenance Fuel supply disruptions	\$65/MWh delivered energy
Electrified Mobility	Lower EV battery manufacturing costs and improved performance Distribution delivery capacity for fast charging	\$80/kWh manufactured cost for a battery backup \$104/kW-year storage capital expenditures
Interdependent Network Infrastructure	Grid interdependencies mean that a loss of function and services within these infrastructures can have far-reaching costs and impacts	\$77/kW-year storage capital expenditures
Critical Services	Disaster-related, extreme weather events, and other power outages	\$77/kW-year for reliability applications \$1,392/kW-year for backup generator offset
Facility Flexibility, Efficiency, and Value Enhancement: Commercial and Residential Buildings	Enhancing the overall facility value to the owner, operator, and end consumer	\$85/kWh, \$52/kW-year for commercial and residential buildings
Facility Flexibility, Efficiency, and Value Enhancement: Energy-Intensive Facilities	Enhancing the overall facility value to the owner, operator, and end consumer	\$20–\$52/kW-year for energy-intensive facilities

In its 2022 Biennial Energy Storage Review ("2022 BESR"), EAC examined DOE's implementation strategies to date from the ESGC, reviewed emergent energy storage industry issues, and identified obstacles and challenges for meeting DOE's technology, market, and workforce goals. The EAC provided an extensive evaluation of the status of DOE work on each of the obstacles and challenges it had identified to achieving DOE's goals on each of the ESGC's specified use cases.

This report makes specific recommendations on programs or activities that should be established or terminated to meet DOE's goals of accelerating the development, commercialization, and utilization of next-generation energy storage technologies and sustaining American global leadership in energy storage. This report identifies specific areas in which the EAC recommends DOE focus attention in the coming years. Some of those recommendations address specific actions that the EAC believes would provide great value to all energy storage stakeholders and end-users regardless of their role or the specific electric storage use case in which they may be interested.

I. Challenges to Most Storage Use Cases

In the 2022 BESR, the EAC had separately identified obstacles and challenges to each of the 6 use cases. In developing the 2024 BESR, the EAC has concluded that several critical challenges, outlined below, are broadly applicable to each of the six use cases. The EAC recommends that DOE prioritize progress on addressing these challenges to provide the greatest value across the potential storage value streams.

The EAC would like to see a white paper to share with industry/stakeholders on these challenges so they will be addressed and not repeated (building on lessons learned earlier).

A. Physical and Cyber Security

The EAC recommends that DOE conduct a careful assessment of cyber and physical security issues raised by the integration of storage into the electric grid. The EAC recommends the assessment address concerns including security for the supply chain, cyber-vulnerability of grid-edge devices, the SCADA systems required to manage the integration of storage into the grid and into markets, the communications infrastructure required to integrate storage into the grid, and the sensitivity of the personally identifiable information that could be collected in connection with grid-edge applications of storage technologies. Regarding physical security, the EAC recommends that DOE evaluate the physical security considerations for grid-scale storage technologies that could serve as an attractive target for bad actors. DOE consolidates all existing assessments across the Department. CESER, OE, EERE and the labs have done work on this topic, and it would be useful to consolidate and build on existing work.

The EAC further recommends DOE work with stakeholders to mitigate the security risks identified in the assessment. Mitigation will require the development and normalization of best practices and standards. Mitigation may also require federal assistance tracking supply chain threats and ensuring transparency into the supply chain.

The EAC specifically identified the need for a secure data portal to which all relevant stakeholders – such as distribution system operators, transmission operators, and market operators – have access to provide and extract information while ensuring customer privacy needs and data security are maintained. Development of such a portal would require DOE or another organization such as the Electricity Subsector Information Sharing and Analysis Center (E-ISAC) to work with stakeholders to develop the rules of the road around the data elements to be provided, who would have access, and how customer privacy could be maintained.

B. Workforce

The EAC notes that the industry will need to build a strong workforce to support all aspects of storage development, including research, design, manufacturing, integration, maintenance, operation, and safety and failure management (e.g. firefighting battery failure). We must retrain existing employees across the value chain and educate and expand the workforce.

To establish a foundation for this effort, the EAC recommends that DOE identify, with the U.S. Department of Labor (DOL), what kinds of positions are most needed in this portion of the industry, the skills that will be required, skill gaps in existing training programs, and estimate the number of workers needed in each of those positions.

The EAC further recommends that DOE, in coordination with DOL, develop a foundational curriculum, models/tools, standards, system requirements, safety provisions, etc., as needed to adequately prepare the future energy storage workforce. DOE should also work with stakeholders on the common connections to workforce development including informing people about such careers, defining career paths, ensuring connections with academic institutions to educate students on competencies, creation of apprenticeship Programs, and the like.

C. Safety

The EAC identified safety as an ongoing barrier across all storage use cases. While some battery concerns (fire safety, hazardous gases, and the risks of discharging energized battery cells) are in the news, the EAC sees safety concerns with some other storage technologies, including flywheels. As new storage technologies are developed, DOE and the industry should proactively identify any associated safety issues as well.

The EAC recommends that DOE work with stakeholders to develop effective preventative protocols and procedures for emergency response including requirements for personal protective equipment, containment, neutralization, and clean up measures specific to each storage technology and its individual safety hazards. These procedures need accompanying protocols for specific scales of storage, since the substantive safety risks differ between larger, grid-scale energy storage and smaller residential and transportation storage.

The EAC also recommends that DOE work with stakeholders to clarify jurisdictional responsibilities for hazard prevention and response. It is not clear in some areas where responsibilities fall between siting and code officials, fire officials, electric utilities, and others. Gaps are likely to continue to arise until best practices are agreed upon and normalized.

DOE should provide clear and transparent reporting on these findings to build public and stakeholder confidence in the safety of these resources.

D. Recycling, Reuse, Disposal

The EAC is concerned that the lack of information available to stakeholders about end-of-life options for certain storage technologies could stunt deployment for any business case. This area is particularly important given the limited supply of critical minerals and other supply chain constraints. The EAC recommends that DOE investigate challenges to the recycling, reuse, and disposal of battery electric storage systems. In particular. DOE should fund further research and stakeholder engagement to maximize the potential lifespan of BESS and minimize the environmental and financial cost of recycling and disposal. DOE should further document and share best practices for the recycling, reuse and disposal of BESS and other storage devices.

E. Grid Inertia and Grid Forming and Black Start Capabilities

Energy storage solutions are essential for the future reliability of the grid. Energy storage solutions can provide the same grid support functions that traditional fossil fueled rotating machines provide grid inertia, grid-forming, and black start.

The EAC recommends that DOE continue to work with stakeholders to drive the development, commercialization, and normalization of greater grid support capabilities from energy storage and associated inverter and integration technologies leveraging the differing capabilities of the suite of energy storage technologies.

F. Electric Vehicle Storage Opportunities

The EAC anticipates that there will be a significant percentage of electric vehicles and trucks on roads in the next decade and thus that transportation electrification presents an opportunity to advance the use of vehicle storage devices for system infrastructure and energy storage use cases, as well as improved charging stations for electric vehicles of all sizes.

The EAC recommends that DOE support the contribution that vehicle storage devices can offer not just for transportation electrification, but also for each of the other use cases defined in the ESGC, especially those related to grid reliability and resilience.

G. Regulatory Clarity

The EAC recommends that DOE provides better regulatory clarity around lagging standards and compliance e.g. compliance with Institute of Electrical and Electronics Engineers (IEEE) standards 1547-2018 and 2800-2022. DOE should expedite efforts to remedy the lack of substantive, current rules and standards governing grid connected inverter-based resources (IBRs) as much existing information is lagging or obsolete.

H. Technological Risk

The EAC recommends that DOE fund more R&D to understand grid behavior under high IBR penetration and to disseminate existing knowledge from initiatives such as bidirectional charging pilots.

I. Storage Valuation

Storage technologies provide many benefits to the grid and stakeholders, but in many instances the value that they provide cannot be monetized. Thus, the payback for certain applications may not be justified, even though there is significant value being provided. The EAC recommends that DOE create quantitative tools for end-users, regulators and markets to recognize the magnitude of storage-related benefits and implement appropriate compensation for those benefits.

In addition to specific benefits that need to be valued to be monetized, the EAC also believes that one barrier to more widespread commercialization of storage technologies is the fact that storage crosses traditional boundaries between generation, load, and transmission. In most centralized and bilateral wholesale electric markets, this limits storage to acting in only one category (e.g., only as generation) and prevents storage from offering services and monetizing benefits in all three categories. For example, a storage facility can provide significant congestion relief at certain nodes, and so is categorized as a transmission resource, even though it can simultaneously time-shift energy and sometimes act as load and generation in different times. The EAC recommends that the DOE provide guidance on how storage may provide value across these categories and how it can be properly remunerated for those benefits.

II. Priority Challenges for Specific Use Cases

The EAC identified several priority areas of the existing use cases that US DOE should address. These are highlighted below.

A. Facilitating an Evolving Grid

1. Addressing lagging standards and compliance e.g. compliance with Institute of Electrical and Electronics Engineers (IEEE) standards 1547-2018 and 2800-2022
2. Ensuring batteries are valued appropriately in the market for the services they provide (e.g. storage can optimize the integration of intermittent resources and mitigate errors in load and supply forecasting). Better forecasting allows storage to deliver more value by allowing stakeholders to dispatch storage more effectively.
3. Determining the cost of investing in new technologies versus alternative investments (e.g. providing better payback models and/or planning tools to determine battery size and placement)
4. Addressing the ability to blend electric/gas resources and define technologies within scope
5. Identifying market opportunities
6. Addressing storage technology life extension, end of life decommissioning needs and high network upgrade costs
7. Identifying market uncertainties for long-term investments, as for resource adequacy and reliance of foreign resources
8. Providing regulatory certainty for storage definitions and roles, particularly whether storage needs to be treated as either generation, T&D, or load or how it can operate and be compensated in multiple roles near-simultaneously
9. Understanding the role of storage to support grid adaptation for high DER penetration and grid behavior under high IBR penetration
10. Assessing how to quantify and express the values of size, locational, financing, and speed flexibility for storage deployment compared to slower, chunkier grid additions such as transmission and generation.

B. Critical Services

1. Using storage to support resilience for critical facilities and communities.
2. Identifying the suite of critical facilities and services (e.g., water and wastewater, traffic lights, community shelters) that can use storage to support continuing operations during extreme

weather, Public Safety Power Shutoff operation, and other community resilience challenges, and developing guidelines for how to size and use storage for these purposes.

1. Identifying priority storage applications for community critical services. For instance, using storage to keep stop lights and streetlights operating during reliability events (e.g., provide batteries on street corners, because many accidents during outages are associated with street light outages)
2. Educating end-users about safe battery installation and operation. Many critical service centers are concerned about battery fire safety.
3. Providing data on the cost of storage for critical services vs. alternative options
4. Ensuring regulations and incentives allow storage to co-purpose

C. Serving Remote Communities

1. Providing supporting data for utilities and other key stakeholders about how storage can provide better access to grid resources in remote communities to enhance grid resilience
2. Ensuring that Interoperability of solutions does not require a highly sophisticated trained workforce
3. Identifying ways to reduce deployment costs or educate end-users about the storage value in remote communities
4. Identifying ways to address the lack of economies of scale, costly operation and maintenance/warranties, and needed costly circuit upgrades

D. Flexibility and Integration of All Loads

1. Enabling market access for storage ancillary services
2. Ensuring storage can be flexible and able to integrate all loads, Including electrified mobility, energy intensive facilities, and individual customer loads
3. Ensuring that EVs used as electricity storage devices can serve many loads effectively
4. Understand how storage can be used to support energy intensive, large energy loads such as data centers and other industrial centers such as cement, water pumping, and crypto mining
5. Assessing whether data center investments in energy resources can help ensure continuity of services, as by inclusion in the fleet of supply and demand resources that can be deployed under emergency conditions to support grid reliability and resiliency
6. Developing medium scale distributed energy storage options and lower cost communication tools
7. Providing data and/or modeling that supports a) the proper valuation for integrated services, b) that storage can make customer loads flexible and grid friendly, and c) supports co-optimization between electrical, thermal, data, and communication needs

III. Overall Recommendations

A. Storage within a Broader Context

The EAC recommends DOE expressly recognize that promoting or advancing storage is not a goal in and of itself. Rather storage represents a suite of potential resources that can be implemented and operated to enhance energy sector and community safety, reliability, and affordability.

This is inherent in the ESGC's development of use cases. DOE clearly understands that industry and consumers will deploy diverse energy storage solutions to serve specific purposes where storage can provide value. Nevertheless, ongoing acknowledgement of the broader context will help DOE discuss and design energy storage work in a manner that recognizes other options available to the grid and help stakeholders understand their relative merits, costs, and drawbacks. This should help both DOE and industry stakeholders prioritize investments.

Some of the most significant issues facing storage aren't specific to storage technologies themselves but rather arise from the challenges from integrating all types of energy storage solutions and durations of charging and discharging into the grid and with other technologies. Many of the issues that need to be resolved for storage, such as developing common standards for interconnection, the operations of inverters to provide net benefits to the grid, and modeling the behavior of diverse energy storage solutions and inverters within the grid are high priorities for all evolving grid technologies, not just storage along.

B. Definition of Storage

The EAC recommends that DOE acknowledge, enumerate, and consider including in its storage efforts the broad range of technologies that can fit under that umbrella, including power-to-power, power-to-heat, and power-to-grid. DOE should look at all forms of storage, including diverse battery chemistries, air and flow batteries, compressed air, liquid air, flywheels, capacitors, supercapacitors, rotational inertia/synchronous condensers, geothermal storage, thermal energy, and chemical storage. Each storage technology offers different values in different contexts.

The EAC recommends that DOE and stakeholders be clearer about the specific storage technologies we are discussing in different potential storage deployment contexts to encourage a finer look at the diversity of technologies and the importance of varying storage durations to meet diverse customer needs. Different storage types can provide varying services over different timeframes at different costs, and each storage type brings its own material science, supply chain, financing, workforce, and operational challenges and opportunities. Speaking generically about "energy storage" will almost always undermine clarity and the overall benefits provided.

C. Cost Targets

In the ESGC, DOE established specific cost targets for storage in different use cases and has invested resources to pursue those targets.

The EAC recommends that DOE publish updated status information for the specific storage costs addressed in the ESGC showing where the costs of storage were at the time the targets were set, where the costs are today, and where new targets should reasonably be established for storage to be a cost-effective resource for the specified end-use.

In addition, the EAC recommends that DOE provide its best data-driven assessments of current and future energy storage technologies and likelihood to reach the new targets. Similarly, DOE should estimate when different energy storage technologies are likely to reach each stage of commercial readiness.

An honest and critical assessment of when different storage technologies will reach target costs and different development levels is essential to policy makers, investors, and other industry stakeholders who must make decisions today about the long-term investments required to ensure power is safe, reliable, and affordable in the near and long-term.

D. Lessons Learned

DOE has invested significant time and money in a wide range of storage projects. The challenge for policymakers and industry stakeholders is to access the extensive, valuable lessons learned from DOE's hard work. The EAC recommends that DOE increase its efforts to convert its research results into accessible lessons learned so stakeholders and the industry can more effectively leverage these lessons into current and future success. It would be beneficial to understand, for example:

- Which research paths have proved fruitful or not, so stakeholders know when to expect the new technologies or other developments to be commercialized within the near term and which will not?
- Which approaches to deployment of storage and associated technologies worked well for those participating in studies and should be emulated and which failed and should be avoided?

Given the wide range of DOE work in this area, the EAC is confident that DOE has a tremendous amount of valuable information.