ELECTRICITY
ADVISORY
COMMITTEE

2022 Biennial Energy Storage Review

Recommendations for the U.S. Department of Energy

FEBRUARY 2023

Introduction

This report fulfills the duties allocated 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." The 2022 Biennial Energy Storage Review serves the purpose defined in EISA Section 641(e)(5) and presents the Subcommittee's and EAC's findings and recommendations for DOE.

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 had never had a comprehensive strategy for addressing energy storage. In its 2020 Biennial Energy Storage Review, EAC supported the development and implementation of the ESGC, identifying its key strength as its cross-cutting approach to coordinating energy storage-related research, development, and demonstration activities across DOE offices.

In this report, EAC examines DOE's implementation strategies to date from the ESGC, reviews emergent energy storage industry issues, and identifies obstacles and challenges for meeting DOE's technology, market, and workforce goals.

Energy Storage Grand Challenge Tracks

The ESGC establishes topline 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 per 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 is taking 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	$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 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		$20–$52/kW-year for energy-intensive facilities

Approach

EAC conducted a months-long review of obstacles and challenges facing the energy storage industry to determine areas of pressure and pain, and to assess whether DOE was addressing these obstacles and challenges in its funding, policy, initiatives, and other efforts. EAC conducted a review internally with energy storage stakeholders and conducted outreach to external energy storage industry stakeholders to gain additional insights.

The EAC review process was organized around the technology development use cases described in the ESGC to identify key obstacles and challenges to the achievement of the DOE goals and activities in the five tracks. Organizing the review by use case allowed for more efficient stakeholder assessments and industry interviews as most market participants are focused on the deployment of discrete market solutions for targeted use cases.

The tables on the following pages gather and organize the obstacles and challenges identified through this process and provide an assessment regarding whether the obstacle or challenge is being addressed by DOE efforts. The tables include the following:

- **Obstacles and challenges identified.** A summary description of the obstacle or challenge facing the energy storage industry from the perspective of industry and stakeholders, categorized by the cross-cutting areas of costs, benefits, process, operations, information, and safety.
- **Track.** A categorization of which of the five ESGC Tracks the obstacle or challenge is most closely associated with.
- **Status.** The EAC's assessment of whether the obstacle or challenge is currently being addressed by DOE's efforts.

Findings (in tabular form)

Facilitating an Evolving Grid

The ability of the U.S. electric power system (i.e., the electric grid) to reliably meet customer demand is crucial to our economy and national security. The increasing adoption of variable renewable energy (VRE) and dynamic changes in customer demand, as well as stresses from weather, physical threats, and cyber threats, have highlighted how enhanced grid flexibility can ensure the continued reliability, resilience, and security of the electric power system.

Obstacles and Challenges Identified	Track	Status
Cost Issues		
High cost of long-duration storage. Energy storage to supplement VRE during outlier days could require long-term storage, which at present prices can be very costly relative to other solutions.	Tech. Development	In Progress
Cost vs. alternatives. Because the levelized cost of various storage technologies varies considerably and are at different stages of technical readiness level, some are better suited to certain use cases than others. Some technologies are more economically suited to near-term applications, while some hold promise for the future, which should be considered across the portfolio.	Tech. Development	Planned
Costly warranties. Lack of or the expense of market instruments to provide warranties/guarantees for early commercial projects.	Tech. Transition	Not Addressed
Costly commercial debt. Lack of or the expense of commercial debt to support early commercial projects with technology risk.	Tech. Transition	Not Addressed
High network upgrade costs. Storage is assigned unnecessary and unreasonably high network upgrade costs in interconnection studies by erroneously assuming that it will be dispatched in scenarios in which it will never operate.	Policy and Valuation	Not Addressed

Obstacles and Challenges Identified	Track	Status
Grid adaptation to high distributed energy resources (DER) penetration. The increased interconnection of DERs will increase utilities' need for new equipment, processes, software systems, and standards, including monitoring, metering, telemetry, bidirectional devices, reclosing/curtailment devices, and back-end and front-end systems. Utilities also will need sophisticated algorithms to properly integrate DERs into the resource dispatch equations without the violation of system thermal loading, voltage, or stability limits.	Tech. Transition	In Consideration
Need for higher round-trip efficiency. Stand-alone energy storage and paired storage with renewable resources require multiple charging and discharging cycles so round-trip efficiency is important.	Tech. Development	Planned
Inflationary pressure. The Inflation Reduction Act of 2022 is providing some financial relief to stand-alone storage developers; however, as project development costs across the board continue to increase, keeping projects affordable will continue to be a challenge.	Manu. and Supply Chain	In Progress
Supply chain delays. Delays in procuring the sub-tier components of energy storage equipment, increased regulations in shipping energy storage equipment, and changes in Battery Energy Storage Systems (BESS) technology that have led to a halt in the manufacture of older BESS models have all contributed to delays in the deployment of energy storage.	Manu. and Supply Chain	In Progress
End-of-life/decommissioning needs. Decommissioning costs/value must be considered upfront but are unclear. A criteria for end-of-life condition needs must be determined and standardized.	Tech. Transition	Not Addressed
Reliance on foreign resources. Reliance on foreign resources, particularly for lithium-ion battery mineral production, underscores the need for improved recycling and reclamation, more efficient use of resources, and domestic mining production.	Manu. and Supply Chain	In Progress
Lack of a domestic workforce. Addressing the need for a domestic labor force for engineering, manufacturing, and maintenance.	Workforce Develop.	In Consideration

Obstacles and Challenges Identified	Track	Status
Lack of qualified battery disposal servicers. A lack of qualified battery disposal and recycling services, with approved processes, make bringing on new BESS risky with no exit plan or understanding of time and the cost needed to retire systems.	Workforce Develop.	Not Addressed
Benefit Issues		
Value. Lack of markets, incentives, and valuation of the full range of services that energy storage can provide.	Policy and Valuation	In Consideration
Ancillary service value. Lack of separately identified ancillary service markets or payments.	Policy and Valuation	Planned
Market uncertainty for long-term investments. It is unclear whether the markets provide enough long-term assurance to asset developers and financial institutions to drive investments that will be available over the long term.	Policy and Valuation	Not Addressed
Lack of clarity regarding the resource adequacy use case. Rules governing the way that storage is used to meet resource adequacy are under development but need clarity and uniformity.	Policy and Valuation	Not Addressed
Unclear payback models. Revenue models for peak shifting, seasonal load shifting, and other capabilities are not certain.	Tech. Development	Not Addressed
Benefits are not valued in regulated environments. All potential benefits of long-duration energy storage are currently not being valued in the regulated deployment scenarios as storage is siloed to perform either generation, transmission, or distribution benefits.	Policy and Valuation	Not Addressed
Process Issues		
Interconnection queue backlogs. Significant	Policy and Valuation	In Consideration

Obstacles and Challenges Identified	Track	Status
interconnection queue backlogs are creating extensive delays in getting projects on the system, even where those projects can alleviate integration issues.		
Permitting time. Local permitting delays and misalignment with interconnection schedules delay projects.	Policy and Valuation	Not Addressed
Accountability gaps for reliability/resilience. Lack of accountability for the reliability and resilience of the electric grid as the number of parties with responsibility continues to increase.	Policy and Valuation	Not Addressed
Lack of clarity in the Federal Energy Regulatory Commission (FERC) rules. FERC/regional transmission organization (RTO) regulatory rules about storage classification/functionalization and cost recovery (from both market and cost-of-service regimes) need clarity and may limit resource operations and deployment, including the use of energy storage as transmission assets.	Policy and Valuation	Not Addressed
Unclear compliance with Institute of Electrical and Electronics Engineers (IEEE) Standards 1547™-2018 and 2800™-2022. These standards are the backbone for DER integration for the distribution and transmission system, respectively. Given the volume of projects, how do we ensure that utilities are in compliance with the standards?	Policy and Valuation	Not Addressed
Gap in the market model for hybrid resources. Proper market models that allow hybrids to provide all of the services that they are capable of are critical. Order 841 recognized this for storage; however, hybrids were not included in this and there is a gap/need.	Policy and Valuation	Not Addressed
Lack of transparency of distributed storage. Storage is well-suited for the distribution grid and Order 2222 opens up the potential for aggregated distribution facilities to participate in the wholesale market. However, there is still work to be done to realize the vision of Order 2222 and increase the transparency of distributed storage assets on the distribution system.	Policy and Valuation	Not Addressed

Obstacles and Challenges Identified	Track	Status
Information Issues		
High-quality operational data. Collection and availability of high-quality operational data to improve safety, reliability, performance, and cost.	Tech. Transition	In Progress
Lack of resilience analytics. There is a need for system-level data analytics, including geographic information system (GIS) location data, historical outages, and local power system design, which can identify opportunities to utilize energy storage for local system resiliency.	Tech. Transition	Not Addressed
Reliability analysis gap. There is a need for additional analysis on the impact of shutting down currently operating generation units and replacing them with renewable and/or energy storage assets. Proper analysis should include hour-by-hour resource adequacy assessment, including available energy from VREs.	Tech. Transition	In Progress
Macro-energy storage analysis gap. Lack of analysis to determine the amount of energy storage needed, where it is needed, how much power duration is needed, whether the projected availability matches the needs, and the costs associated with those needs. Analysis should include 24/7 capacity, reserve margin, energy, and resilience needs, as well as load growth and distributed storage potential associated with EVs and other electrification loads.	Tech. Transition	Planned
Regulator education. Lack of dissemination and education on this energy storage analysis to policymakers and stakeholders as they set goals and rules for changes to the electric grid architecture.	Workforce Develop.	In Consideration
Utility/RTO education. RTOs and utilities lack an understanding of the benefits of storage deployed on the grid, separately or in conjunction with generation and other resources, among RTOs and utilities.	Workforce Develop.	In Consideration
Lack of long-duration demonstration projects. Demonstration projects for new longer term storage technologies are needed, including for durations of longer than 4 or 8 hours. The state of the development of longer	Tech. Transition	Planned

Obstacles and Challenges Identified	Track	Status
term storage technologies and their impact on the grid are unclear. The potential for implementing proven long-term storage, such as pumped storage hydro, is barely considered.		
Challenges in modeling storage as load/generation. Lack of uniformity regarding how to model storage that is interconnected as resources and treated as load for certain purposes across different regions. Existing modeling tools also do not properly model all storage capabilities and benefits, such as technology characteristics that affect life cycle vs. degradation and system efficiency.	Tech. Transition	In Consideration
Immaturity of modeling in capturing storage. Modeling the use of storage in economic and reliability modeling requires more development. Production cost modeling platforms do not adequately represent the benefits of the use of energy storage resources with variable resources.	Tech. Transition	Not Addressed
Technical readiness level (TRL) confusion. Lack of universal definitions of TRLs and appropriateness for commercial deployment.	Tech. Development	Not Addressed
Operational Issues		
Difficulty of optimizing with variable energy resources. Optimization is required due to the finite nature of the energy storage capacity but is heavily influenced by the uncertainty in the renewable energy forecast and net load.	Tech. Development	In Consideration
Lack of understanding regarding how to address the high penetration of inverter-based resources. Grid operators and stakeholders are unfamiliar with the technologies and policies that should be considered as the number of inverter-based resources, including energy storage resources, increase. Grid-forming capabilities are needed but are still being developed and no industry standards exist yet.	Tech. Transition	Planned
Uncertain behavior in high inverter-reliant systems.	Tech. Development	Not Addressed

Obstacles and Challenges Identified	Track	Status
The impact on grid stability and reliability are anticipated from relying heavily on BESS technology and inverters for system stabilization and disturbance response. There are several technical reports of large BESS resources not behaving as modeled in actual operation.		
Uncertainty over market commitment to maintenance. Lack of analysis on whether market-driven investors will spend the operations and maintenance (O&M) costs to maintain reliable operation of the assets or make business decisions to shut them down if large O&M costs are required.	Tech. Transition	Not Addressed
Lack of access to grid operational data. Control of and data access to grid assets must be protected at all times. Real-time access to grid assets may not be available to non-utility entities.	Tech. Transition	Not Addressed
Safety Issues		
Unclear regarding the scope of safety Issues. Understanding safety issues related to new technologies through testing and characterization, and the development of prevention and mitigation strategies.	Tech. Transition	Planned
Lack of guidelines for known safety issues. Addressing safety challenges as an industry with appropriate guidelines for public safety, transportation, operator guidelines, and incident response for existing and new technologies.	Workforce Develop.	Planned

Findings: Facilitating an Evolving Grid

The integration of energy storage is an essential ingredient to ensuring that the U.S. electric power system can reliably meet customer demand; integrate carriable renewable energy; and ensure continued reliability, resilience, and security. Across the country, the industry working to support this integration is facing significant challenges with adding energy storage to the system in time to meet the needs of the system. The industry is facing headwinds from rising component and system costs due to inflation, significant delays due to foreign and domestic supply chain backups, uncertain market payments and valuation, and an absence of pathways to provide needed grid services.

For adopters and implementers, high non-technology costs add additional barriers, including network upgrade costs, costly warranty and maintenance agreements, high-cost commercial debt, safety and hazard prevention, and end-of-life disposal costs, which are largely unpredictable and can hinder deployment.

Existing analysis has shown a significant need for long-duration storage to address seasonal variability in renewable energy production and to increase resilience, as recently documented by the California Independent System Operator, documenting the need to not only shift solar production during the day, but also between months. Yet the costs for existing long-duration storage technology continue to significantly exceed the value of its market role.

As policymakers seek to ramp up energy storage deployments and address system needs within their states and systems, there are key information gaps that hinder progress. Policymakers and market participants need more information on the use cases of storage to address state and local energy goals, real-world demonstrations, better tools to integrate energy storage technology into planning, analytics to be able to quantify the impact of resilience, and best practices and guidance for integrating energy storage into planning and markets.

As more storage deployment ramps up, system operators, asset owners, and local governments would benefit from greater assistance to reduce interconnection and permitting delays.

National policymakers and market players need a better understanding of the actual technical and market need for energy storage on the system as a whole, over time, as changes in the resource mix and the quantity of the capability of dynamic load evolve and need to understand whether there is enough manufacturing, raw material, infrastructure, workforce, and component availability to be able to meet the demand.

Over the long term, system operators, policymakers, and market participants will need to have a greater understanding of how inverter-based resources affect the grid at high penetrations, and how to develop operational agreements with third-party energy storage asset owners and operators for system protection.

Electrification is expected to add load growth to a system lacking significant investments in transmission for decades. Flexibility rate design in procurement, ownership, and asset management would allow transmission and distribution utilities to mitigate bottlenecks now and better plan for large transmission capital expenditures where they are needed the most. DOE should seed state and RTO efforts to value and operationalize flexibility to serve this market need.

Serving Remote Communities

Up to a billion people in the world do not have access to electricity. Island, coastal, and remote communities that are disconnected from the bulk power system pay a premium for electricity due to the fuel logistics and maintenance associated with diesel generation. In remote communities subject to extreme weather conditions, fuel supply disruptions are a major risk factor.

Obstacles and Challenges Identified	Track	Status
Cost Issues		
Overall system cost. Lack of cost-effective solar+battery systems within a reasonable footprint serving the need for a multiday run time (ideally) or at least 8–10+ hours without diesel backup.	Tech. Development	In Consideration
Lack of risk mitigation tools. Utilities need to cost-effectively come up to scale with long-duration storage and be given ways to manage the risk as it is hard to invest in new technology.	Tech. Transition	In Consideration
Costly O&M and warranties. Preventative maintenance and warranties are expensive, ineffective, and often ignored by end users in remote locations. Remote vendor support is costly and often untimely, and vendors' and end users/operators' employee turnover disrupts the continuity of O&M.	Tech. Transition	Not Addressed
Costly deployments. The cost of implementing any sort of development in remote areas is usually very high, so there could be financial hurdles in deploying energy storage in microgrid use cases.	Tech. Development	Not Addressed
Costly circuit upgrades. Circuits in remote areas can span long distances and have small conductor sizes with uneven load distribution. DER wishing to connect on these lines may thus be faced with substantial upgrade costs to rebuild and/or reconductor these circuits for DER integration.	Tech. Development	Not Addressed

Supply chain delays. Developers have reported difficulty in obtaining the interconnection transformers needed for 10-MW projects.	Manu. and Supply Chain	In Progress
Costly communication needs. Grid infrastructure, including communication, creates a cost barrier for getting batteries to remote communities. Fiber is needed for secure control and direct transfer trip (DTT).	Tech. Development	Not Addressed
Lack of economies of scale. Smaller community projects mean higher costs due to a lack of economies of scale.	Tech. Development	Not Addressed
Benefit Issues		
Financing. Difficulty lining up financing based on an uncertain benefit/revenue stream.	Tech. Development	Not Addressed
Process Issues		
Community capacity. Community capacity can be a barrier to appropriate resource allocation and engagement: Apply the appropriate resources to remote community needs based on the capacity and maturity level of the clients; take baby steps for organizations/communities with low capacity and deploy pilots and demonstrations for communities/organizations with adequate capacity. Community size/population is not necessarily reflective of community resource capacity.	Tech. Transition	Not Addressed
Regulatory uncertainty. The Federal Energy Regulatory Commission/RTO regulatory rules about how storage could be used as a distributed energy resource or to displace transmission to serve rural communities are evolving and/or untested.	Policy and Valuation	In Consideration

Operational Issues		
Unclear requirements. Remote community projects often do not have a straightforward understanding of the system requirements needed for an energy storage system.	Tech. Development	Not Addressed
Interoperability. Systemic lack of expertise in integrating energy storage into microgrids among the vendor, system integrator, and end user. Energy storage nomenclature is unique and standard communications and operational control algorithms are needed.	Tech. Development	Not Addressed
Community acceptance. There needs to be some level of community understanding and acceptance of energy storage becoming a primary resource within the community itself, which could be a challenge if there are not enough educational and community outreach resources.	Tech. Transition	Not Addressed
Control systems. There is a need for advanced power system architectures and control systems for remote communities.	Tech. Development	Not Addressed
Information Issues		
Complexity. While diesel-based microgrids are a proven and known solution for remote communities, operation with inverter-only solutions will be subject to the finite energy nature of the storage and the complexities of reliable operation with only inverter-based resources. Therefore, it is important to provide stakeholders with these considerations in deciding on the energy resource options for microgrids.	Tech. Transition	In Consideration
Modeling community needs. Small rural communities require a better understanding of their energy storage needs. What capacity and energy size are needed? What is a storage usage/cycle profile? What is their backstop resource for reliability and resiliency?	Tech. Transition	Not Addressed

Operational data availability. Collection and availability of high-quality operational data to improve safety, reliability, performance, and cost.	Tech. Transition	In Progress
Safety Issues		
Safety guidelines. Addressing safety challenges as an industry with appropriate guidelines for public safety, transportation, operator guidelines, and incident response for existing and new technologies.	Workforce Develop.	Planned

Findings: Serving Remote Communities

Energy storage can serve a near-term and important role in meeting the balancing needs of remote communities that are disconnected from the bulk power system and operate as a microgrid. While the benefit of integrating energy storage into such systems is readily apparent, there are additional cost and risk burdens faced by these communities that can stand in the way of energy storage project deployment.

Remote communities face high costs from the recent explosion in fuel costs and are more vulnerable to supply disruptions. Additionally, they face cost pressures related to deployments, O&M, communication infrastructure, and economies of scale simply due to their size and their distance from workforce and supply hubs. Remote communities often face higher costs to upgrade distribution circuits to accommodate energy storage due to their age and designed capacity for when they were built. Similarly, remote communities often do not have embedded, high-cost system integrations, such as a supervisory control and data acquisition (SCADA) or distributed energy resources management system, in place that can be leveraged as part of a deployment.

Remote communities also have less ability to manage the risk of a project as a single energy storage project can represent a significant cost in relation to their budget and can serve as the primary backstop for resiliency. Remote communities need additional financial tools to mitigate their risk exposure. Such communities also need additional information and data to be able to navigate and model competing storage technologies against community needs.

Remote communities often lack the internal capacity of larger utilities, cities, and systems to pursue projects and manage projects that are innovative and complex in nature. Many rural cooperative and municipal utilities may be dependent upon one or a handful of individuals that are responsible for most operations. Additional capacity and support are needed for energy storage deployments that rely on complex arrangements, such as in a microgrid or to integrate with other systems.

Finally, as the federal government invests to expand access to broadband to rural areas, there is an opportunity to coordinate broadband infrastructure deployment with upgrades to remote community monitoring and data acquisition (e.g., SCADA) needs.

Electrified Mobility

Increasing electrification in the transportation sector can be facilitated with large-scale, reliable, high-power, and cost-effective charging infrastructure that enables charging times equivalent to that of refueling at a traditional gas station. Because high-power DC fast charging can stress the delivery capacity of the local distribution grid, this new charging infrastructure should minimize any negative grid impact and optimize operations with the grid and other end uses, including buildings. Beyond charging infrastructure, energy storage systems also will be necessary for the EVs themselves. Lower manufacturing costs and improved performance of domestically produced EV batteries can facilitate widespread adoption and further establish American leadership in energy storage.

Obstacles and Challenges Identified	Track	Status
Cost Issues		
Lack of access to the electric grid. Rural areas often lack adequate grid capability for EV charging infrastructure.	Tech. Development	In Progress
Post-life recycling. Lack of post-life recycling clarity creates a disincentive for communities to make the switch given the unknown future externalities from the waste stream.	Tech. Transition	Planned
Limited grid capacity. Limited transmission, subtransmission, and distribution feeder capacity limits the ability of EV and energy storage systems to charge from the grid and export energy to the grid.	Tech. Transition	Not Addressed

Lithium supply chain. Supply chain pressures are high for lithium for use in EV and other mobile applications.	Tech. Development	In Progress
Domestic battery production. A lack of low-cost, domestically produced battery technology.	Tech. Development	In Progress
Costly communication needs. Grid infrastructure, including communication, creates a cost barrier to networked EV charging and grid management. Fiber is needed for secure control and DTT.	Tech. Development	Not Addressed
Lack of economies of scale. Smaller utilities and ecosystems mean higher EV charger and infrastructure costs due to a lack of economies of scale.	Tech. Development	Not Addressed
Benefit Issues		
Lack of time- and locational-sensitive rates. Better incentives also will be needed to encourage the end user to charge and feed power back to the grid at optimal times.	Policy and Valuation	Not Addressed
Low charger utilization. It is hard to justify the economics of storage with today's lower charger utilization.	Tech. Development	In Progress
Vehicle-to-grid value proposition. More data are needed on the value proposition for storage for discharging onto the grid.	Tech. Development	In Progress
Proper pricing for EV energy storage for emergencies. With regard to properly pricing incentives for EVs to trade "miles for dollars," it is anticipated that the incentive will need to be higher than for standard batteries because communities typically "top off gas/store gas."	Tech. Development	In Progress

EV adoption equity. Addressing policy issues in terms of ownership and charger availability in disadvantaged communities to increase the adoption rates of EVs overall as swiftly as possible.	Policy and Valuation	Planned
Process Issues		
Following standards. Technical standards for UL 9540 (Standard for Safety of Energy Storage Systems and Equipment) and UL 9540A (Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems) are being circumvented.	Policy and Valuation	Not Addressed
Permitting delays. Authorities having jurisdictional review and permitting authority are in need of standardization and streamlining to expedite permitting.	Policy and Valuation	Not Addressed
Federal funding reporting. Complex and burdensome reporting and financial administration for federal funding targeting EVs and battery grid services may create a disincentive to leverage federal funds.	Tech. Transition	Not Addressed
Cost allocation and rate design. States are struggling with identifying methods for allocating and recovering costs for EV charging infrastructure used by only a few when funded by ratepayers.	Policy and Valuation	Not Addressed
Operational Issues		
Communication standards. There is a need for communication protocol standardization in a multivariate world of EV manufacturers and EV service providers.	Tech. Development	In Consideration
Information Issues		

EVs are undervalued for resiliency. Leveraging mobile storage as a DER to mitigate pending disasters (e.g., charging EVs and mobilizing them to high ground in advance of a hurricane to power emergency shelters, charging and staging before or during an event to facilitate evacuations, providing vehicle-to-home electrification to ride through a storm or event related outages).	Tech. Transition	In Consideration
Lack of nodal carbon-intensity data. EVs can be used as an active storage device to participate in reducing the carbon intensity of the grid; however, better hourly (even sub-hourly) nodal data are needed.	Tech. Transition	In Consideration
Total Cost of Ownership tools. Barriers to adoption around fleet electrification stem from fleets lacking the know-how/resources to perform an adequate total cost of ownership comparison with their existing fleet, and none includes an analysis of paired storage or vehicle-to-grid/vehicle-to-home/building capabilities.	Tech. Transition	Not Addressed
Operational data availability. Collection and availability of high-quality operational data to improve safety, reliability, performance, and cost.	Tech. Transition	In Progress

Findings: Electrified Mobility

Electrified mobility provides a significant opportunity to reduce fossil fuel emissions and dependence and improve the net energy efficiency of transportation modes. Rising fossil fuel costs and increasingly uncertain supply chains can be alleviated by locally sourced and more stably priced electricity. While emerging vehicle-to-grid (V2G) and vehicle-to-home/building (V2H/V2B) technologies offer the promise of a more flexible and resilient grid that can benefit from the distributed and bidirectional storage of electrified transportation, limitations in charging infrastructure and legacy grid structure will require significant investments to facilitate electrified mobility.

Rural and remote areas are often served by small utilities that lack the staffing capacity to develop charging networks and rate structures to facilitate time, location, and resource variations. Economies of scale can deter rural areas with low public charger utilization. Urban areas face a challenge in locating and deploying charging infrastructure as both the congestion of distribution networks and inadequate parking availability can hamper the siting of charging stations. Both rural and urban environments need near-term financial resources to upgrade existing distribution network capacity and storage, as well as planning tools to support that rapid roll-out, including standards, siting, rate designs, future scaling, and information about V2G/V2H/V2B capabilities.

Policy improvements are needed to facilitate standards development and compliance. Timely siting and permitting reviews and approvals, and reasonable, transparent, and simplified fee and tax structures can further accelerate the adoption of electrified mobility. New pricing structures should be developed to properly allocate the costs of infrastructure and the benefits of the distributed energy storage capabilities for meeting emergency needs and to facilitate the life cycle cost of ownership comparisons with legacy transportation vehicles and fleets. Developing or accessing grid and vehicle operational data will be essential for planning and valuation purposes.

DOE should expand its role in facilitating V2G programs and in helping to gather and analyze data coming from existing V2G programs to better understand whether and how vehicle batteries can be integrated onto the grid and to answer other questions identified by stakeholders (e.g., grid-forming inverters, valuation, battery standardization, rate structure, timing).

Electrified mobility will benefit from supply chain improvements, including the domestication and diversification of electric energy storage technologies to alleviate lithium and other supply bottlenecks. Provisions for end-of-life recycling, repurposing, or disposal of mobile energy storage assets will provide more clarity to communities and remove the disincentives to support a migration to electrified mobility.

Interdependent Network Infrastructure

The operation of the electric grid depends on other infrastructure sectors, including natural gas, communications, information technology, water, and financial services. The loss of function and service within this infrastructure due to energy delivery disruption can have far-reaching effects on health, safety, and costs for end users. These interdependencies elevate the importance of sustaining the normal operations of critical infrastructure amid the short-term disruption of energy inputs.

Obstacles and Challenges Identified	Track	Status
Cost Issues		

Costly communication needs. For resiliency and security, electric utility communication networks need isolated, secure networks for SCADA and smart grid system control, and dark fiber as a redundant/emergency path for Telco communication systems.	Tech. Transition	Not Addressed
Lack of economies of scale. Smaller utilities and ecosystems with few touch points for interdependencies bear relatively high costs for infrastructure due to lack of economies of scale.	Tech. Transition	Not Addressed
Benefit Issues		
Lack of payback for BESS backup power role. Backup power may not offer sufficient payback, so there is a need for ways to utilize BESS for more services while also supporting the backup power role.	Policy and Valuation	In Progress
Ignored analytics. Current research shows that only 30% to 40% of the analytics captured are used. Advise utilities and other interdependent infrastructure users to increase this percentage to support savings in O&M and infrastructure.	Workforce Develop.	Not Addressed
Process Issues		
Lack of incentives for critical reliability. Limited storage, buffers, and alternatives for critical dependencies and the lack of market and regulatory incentives to develop them are barriers to reducing interdependence or strengthening key elements of that interdependence.	Policy and Valuation	Not Addressed
Information Issues		

Supply chain interdependencies. There is a lack of clear understanding of the interdependency of the supply chain for natural resource constraints, heating fuels, communications, information technology, water supply, sewage treatment, financial services, and electricity.	Manu. and Supply Chain	Planned
Analysis of prolonged disruption. There is a lack of understanding about the interdependency of support roles and a lack of quantitative analysis regarding the impact of prolonged disruption of heating fuel delivery, communications, information technology, water supply, sewage treatment, and/or financial services to energy resources.	Tech. Transition	In Consideration
Resiliency use cases. There is a need to understand how energy storage can best be used to address resiliency needs for other infrastructure sectors, including communication hubs and water supply.	Policy and Valuation	In Progress
Governance/Operational differences. There is a lack of understanding between interdependent gas and electric industries regarding their respective governance of supply and operations differences (e.g., the incongruity of the natural gas peak design day vs. the electricity daily peak demand).	Tech. Transition	Not Addressed

Findings: Interdependent Network Infrastructure

There is insufficient attention paid to the interdependencies between the electric sector and other infrastructure sectors, such as natural gas, communications and information technology, and water supply, among others. Existing data often are not used fully; supply chain interdependencies and constraints are not systematically explored by the planners, operators, and regulators of the electric grid; and the impact of electric disruptions on other sectors of the economy and other critical infrastructures is not fully understood.

As a result, there is often inadequate investment in some areas, such as information technology and communications, to enhance the system’s resilience. Similarly, the lack of attention paid to existing interdependencies also is hurting clear identification and definition of energy storage value, which, in turn, hinders the ability to develop resilience use cases, revenue structures, and market and regulatory incentives that facilitate the optimum deployment of energy storage.

Critical Services

Sectors that provide critical services include communications, defense industrial base, emergency services, government facilities, and healthcare and public health. An extended loss of power to facilities in these sectors could lead to unacceptable public health and safety risks, especially following disaster-related power outages. Similarly, many companies or manufacturers require the ability to resume and maintain operations in the event of an extended outage. The importance of these services reinforces the importance of sufficient energy supplies to these facilities during an extended outage.

Obstacles and Challenges Identified	Use Case	Status
Cost Issues		
Overall system cost. Lack of cost-effective solar+battery systems within a reasonable footprint serving the need for a multiday run time (ideally) or at least 8–10+ hours without fossil fuel backup.	Tech. Development	In Consideration
Cost vs. alternatives. While multiday energy storage technologies could be cost-effective or warranted in the future for outlier weather patterns or other situations that result in the loss of renewable production for extended periods, other options may have (at least over the next several years) a lower cost or better meet the needs and, thus, also may be evaluated in a portfolio of resources.	Tech. Development	In Progress
Finite resources. Once energy storage is discharged, it needs an energy source to charge it. To provide resilience benefits, the energy storage must stand ready (charged) when needed.	Tech. Development	In Progress
Difficulty to site. The longer duration storage technologies available today are not well-suited for being transported, sited, and installed to support disaster-related needs, such as at community gathering places.	Tech. Development	In Progress
Distribution feeder support. If the circuit/feeder or the related transmission system is out/constrained, storage may not be able to be deployed and assist with an event.	Tech. Transition	Not Addressed

Hardening. Additional cost needed to harden equipment to withstand extreme events if used for critical services/resilience.	Tech. Transition	Not Addressed
Need for different battery characteristics. For disaster backup service, “cycle life” is less critical than “float” charge performance, reliability, fire resistance, and cost-efficiency. The grid-forming capability of the inverters is also crucial for black-start backup services.	Tech. Development	Not Addressed
Lack of economies of scale. For smaller communities and utilities, each critical service is either the only one or one of a few, creating a relatively high cost of storage deployment due to a lack of economies of scale.	Policy and Valuation	In Progress
Benefit Issues		
Lack of payback for backup power. Backup power may not offer sufficient payback. There is a need for ways to utilize BESS for more services while also supporting backup power.	Policy and Valuation	In Progress
Lack of value for resiliency. There is a need to value resiliency, not only as a non-wires alternatives but as a societal impact. There is a need to be able to quantitatively value BESS capabilities in critical locations.	Tech. Development	In Progress
Process Issues		
Inability to co-purpose. Regulatory barriers for broad and holistic deployment of assets (e.g., co-purposing a BESS as an emergency power supply for a nearby hospital, water treatment plant).	Policy and Valuation	Not Addressed
Operational Issues		

Black-start capability. The ability for energy storage facilities to have black-start capabilities is relatively new for end users and often overlooked during specification/procurement and untested during commissioning. However, the use of BESS with grid-forming inverters is crucial to maintaining black-start capability in the near future.	Workforce Develop.	Not Addressed
Deploying mobile storage. There is a need to clarify the rules and restrictions on mobile storage deployment for disaster relief.	Policy and Valuation	Not Addressed
Information Issues		
Climate change impacts. The resilience of grid systems will become more important due to the effects of climate change.	Tech. Transition	Planned
Resiliency use cases. There is a need to understand how energy storage can best be used to address resiliency needs for other infrastructure sectors.	Policy and Valuation	In Progress
Need for an analysis of protection and control. Studies on microgrids also are evolving to ensure that the grid is protected and the microgrid can function properly. More automated analysis of protection and control and ground bank transformers needs to be developed.	Tech. Transition	In Consideration
Lack of resilience analytics. There is a need for system-level data analytics, including GIS, historical outages, and local power system design, which can identify opportunities to utilize energy storage for local system resiliency.	Tech. Transition	Not Addressed

Findings: Critical Services

Energy storage can play a crucial role in maintaining electric services for the critical defense, emergency services, government, healthcare, communications, food distribution, and industrial base sectors. As physical threats and natural disasters increase in frequency and severity, it is important to improve the resiliency of the grid to ensure that critical services can be maintained or recovered quickly.

Historically, these sectors mostly have relied on circuit redundancy and emergency diesel generators with a relatively small space footprint, high energy density, and a long-duration (hours to days) backup power supply. Energy storage technologies are often more expensive, have obscure or prohibitive siting requirements, provide limited-duration storage, and face regulatory barriers.

Critical services can benefit from policy improvements that enable greater adoption of energy storage, including the use of energy storage as an alternative to backup diesel generators and regulatory cost models that allow grid storage to be repurposed for emergency services. Flexible and expedient site permitting can aid in the deployment of storage for critical services. Valuation models for resiliency are needed to assist regulators in setting rates.

New technologies need to be developed to minimize environmental risks, increase storage duration, reduce the footprint of energy storage, and provide black-start and grid-forming services for islanded energy supply to critical services.

Modeling tools are needed to evaluate system-level data analytics, including resiliency metrics for critical services, grid operational data, GIS information, advanced metering infrastructure data, and grid design to optimize the sizing and siting of energy storage. Modeling tools also are desirable for ensuring robust protection and control schemes for both normal grid operation and emergency operations for a degraded grid that needs to prioritize critical services. The role of electrified mobility also should be considered in resiliency planning for opportunities to move storage resources to critical services for emergency support.

Facility Flexibility, Efficiency, and Value Enhancement for Commercial and Residential Buildings

This use case seeks to leverage opportunities to optimize energy production and usage in facilities, especially commercial and residential buildings. Optimized integrated processes can utilize high-performance, low-cost energy storage technologies to enhance the overall facility value to the owner, operator, and, ultimately, the end consumer.

Obstacles and Challenges Identified	Use Case	Status
Cost Issues		
Cost vs. alternatives. Expected costs are still high when compared with typical generation technologies.	Tech. Development	In Progress
Permitting cost. The cost to permit new storage facilities is burdensome.	Policy and Valuation	Not Addressed
Costly communication needs. Extending communications and control networks for grid interaction and transaction creates a cost barrier for commercial and residential facilities for resilience and value enhancement. Fiber is needed for secure control and DTT.	Tech. Development	Not Addressed
Benefit Issues		
Peak reduction incentives. Lack of customer incentives for customer participation in peak reduction services.	Policy and Valuation	Not Addressed
Access to time-variant rates. Lack of customer access to time-variant rates.	Tech. Development	In Progress
Co-optimization. There is a need to coordinate and co-optimize between electrical and thermal needs, particularly in the wake of beneficial electrification and electrical/thermal storage technologies.	Tech. Transition	Not Addressed
Process Issues		
Permitting time. The time and process needed to permit	Policy and Valuation	Not Addressed

new storage facilities are too long.		
Interconnection time. Outdated distribution system interconnection rules are preventing cost-efficient and timely connection of customer-owned, behind-the-meter storage assets.	Policy and Valuation	Not Addressed
Wholesale market uncertainty. Ongoing and open legal and regulatory debates over jurisdictional rights and conflicts in the oversight of customer-owned storage in wholesale and retail markets.	Policy and Valuation	In Consideration
Traditional cost-recovery models. Cost allocation and recovery mechanisms that disincentivize utility and transmission owners from supporting customer ownership of behind-the-meter storage assets.	Policy and Valuation	In Consideration
Siting and social justice. The siting of large battery storage facilities likely will not be in higher income communities due to line-of-sight, storage facility noise, and bulk lithium-ion safety issues.	Policy and Valuation	Not Addressed
Operational Issues		
Real-time market conditions. Industry needs to be able to share marginal prices and DER signals through a common digital interface.	Tech. Transition	In Consideration
Information Issues		
Use cases and tools. Understanding how energy storage can best be used to address customer flexibility—decarbonizing end-use loads while serving customers with higher convenience and comfort at a lower cost.	Policy and Valuation	In Progress
Operational data collection. Collection and availability of high-quality operational data to improve safety,	Tech. Transition	In Progress

reliability, performance, and cost.		

Findings: Facility Flexibility, Efficiency, and Value Enhancement for Commercial and Residential Buildings

Energy storage can play a crucial role in creating facility flexibility, efficiency, and value enhancement for commercial and residential buildings. Energy storage in this segment will support the growth of renewable electric services, as well as potentially create added redundancy for the grid during periods of peak use. As service providers to this energy-consuming segment of the grid work to analyze, source, and develop more renewable distributed energy resources (DERs), they are inhibited with regard to the broader use of energy storage by high installation and use costs, lack of energy market price data, and the current low-performance capabilities of energy storage.

Historically, commercial and residential end users have been able to rely on local, state, and national electric grid cost and use information to know, with reasonable confidence, the economic feasibility and long-term use costs needed to make the energy supply investments to their facilities. However, with the growth in the number of DERs, the sporadic reductions in traditional base power generation, aging grid infrastructure, and inconsistent or absent real-time price signals for determining time-of-use demand savings make greater adoption of energy storage with DERs slower than needed to meet anticipated demand.

Currently, grid operators have a good idea about historic time-of-day energy needs. However, as the grid shifts to microgrids where end users charge energy storage assets (primarily batteries) at unpredictable times, historical data become irrelevant as the grid operational profiles become more variable. Users attempting to consume off-peak energy to charge storage for later use in offsetting peaks may shift the net peak for the operator, inadvertently placing new energy storage load on the grid at new peak times and supplying stored energy to the grid at new off-peak times. The net effect could be higher peaks and lower valleys of energy demand to the grid.

While consumers in some regions of the country can access variable time-of-use utility rates, many parts of the country do not offer these needed options. In regions where time-of-use rates are available, limited energy storage options for the commercial building (middle) market, which represents one of the largest producers of carbon dioxide nationally at approximately 40% of U.S. carbon emissions, hamper timely access to the rates.

In contrast with the limited options for the middle market of commercial and industrial buildings, the smaller residential scale and larger grid scale applications have a variety of storage options. Developing appropriate mid-sized storage options for the middle market of commercial and industrial buildings will accelerate the use of renewable energy sources in the customer segment.

The life cycle of energy storage batteries is a significant and unpredictable risk when developing project financial modeling for commercial and residential buildings. Without reliable, proven data for life expectancy and available power capacity throughout that life cycle, the allocation of investment funds over a 10- to 20-year term becomes a “best guess” and can deter energy storage investments. Field use testing and reporting on new energy storage technology and periodic updates to existing technologies would be beneficial.

New technologies need to be developed to reduce installation, operational, and maintenance costs and increase storage duration performance to support the installation of more renewable energy DERs. Conterminously, new policies and procedures need to be created and applied at the utility level to accurately track new energy storage installations and maintain the situational awareness to co-optimize the interaction of the residential and commercial storage with the grid.

Facility Flexibility, Efficiency, and Value Enhancement for Energy-Intensive Facilities

This use case seeks to leverage opportunities to integrate energy storage within a range of electric power resources and energy-intensive industrial facilities. This subfamily is characterized by significantly higher energy flows than the commercial/residential buildings sector. The nature of how energy is converted and transported in the processes associated with energy-intensive facilities optimization offers potential opportunities for improvement in economics, flexibility, and market diversity.

Obstacles and Challenges Identified	Use Case	Status
Cost Issues		
Lack of dynamic distribution studies. Batteries must be studied at full charging during peak circuit conditions, which limits BESS hosting capacity.	Tech. Transition	Not Addressed
Assessing ongoing demand costs. Analyses often ignore the cost and rate impacts of charging BESS.	Policy and Valuation	Not Addressed

Lack of medium-scale distributed energy storage options. Battery energy storage products have mostly focused on large, utility-scale applications or small, residential systems.	Tech. Development	In Consideration
Quality components. In the mid-size energy storage market, inverters deployed with systems often struggle to stand up to outdoor conditions or require too much additional cost to condition indoors.	Tech. Development	Not Addressed
Lack of economies of scale. Energy-intensive facilities are often custom installations with unique needs and bear relatively high costs for storage infrastructure due to a lack of economies of scale.	Tech. Development	Not Addressed
Costly communication needs. Extending communications and control networks for robust grid interaction and transaction creates a cost barrier to energy-intensive facilities for resilience and value enhancement. Fiber is needed for secure control and DTT.	Tech. Development	Not Addressed
Benefit Issues		
Peak reduction incentives. Lack of customer incentives for customer participation in peak reduction services.	Policy and Valuation	Not Addressed
Access to time-variant rates. Lack of customer access to time-variant rates.	Tech. Development	In Progress
Co-optimization. There is a need to coordinate and co-optimize between electrical and thermal needs, particularly in the wake of beneficial electrification and electrical/thermal storage technologies.	Tech. Development	In Progress

Process Issues		
Standards. There is a need for published and adopted vehicle-to-grid and vehicle-to-home standards.	Policy and Valuation	In Progress
Operational Issues		
Real-time market conditions. The industry needs to be able to share marginal prices and DER signals through a common digital interface.	Tech. Transition	In Consideration
Information Issues		
Tools for combined approaches. Market practice that views electricity output and other output (e.g., heat) separately.	Manu. and Supply Chain	Planned
Locational emissions. Location-specific emission intensity is needed on a forward-looking basis, in real time, and on a historical basis to ensure that you are measuring the impact correctly.	Tech. Transition	Not Addressed
Use cases and tools. Understanding how energy storage can best be used to provide customer flexibility and value and illustrating the flexibility and value with successful use cases will encourage energy storage adoption.	Policy and Valuation	In Progress

Findings: Facility Flexibility, Efficiency, and Value Enhancement for Energy-Intensive Facilities

Energy storage will play a crucial role in creating facility flexibility, efficiency, and value enhancement for energy-intensive facilities. Energy storage in this area will support the growth of renewable energy, as well as create added redundancy for the grid during periods of peak use given their larger capacities. As service providers for this energy-consuming segment of the grid work to analyze, source, and develop more large/utility-scale DERs, which can help to maintain the needed supply reliability, they are inhibited in the broader use of energy storage by the lack of access to time-variant rates/real-time energy market price data. Developing use cases for how energy storage can practically address energy-intensive customer and grid operating flexibility in support of the decarbonizing of end-use loads will further encourage the deployment of storage to energy-intensive facilities.

Energy-intensive facilities have historically been able to rely on predictable daily load profiles and rate models to assess asset investments in their facilities. The evolution of the grid to more dynamic and unpredictable profiles and rates makes it increasingly complex to develop benefit/cost models to encourage broader energy storage adoption for energy-intensive facilities.

Regulatory requirements impose additional barriers on the operational flexibility and retail, wholesale, and behind-the-meter market access of energy storage for energy-intensive facilities.

As the grid continues to shift to more microgrids/DERs where end users feed into the grid and charge/discharge energy storage assets at varying times, grid performance becomes less predictable. Energy-intensive facilities and the utilities servicing them will need more tools to provide real-time situational awareness and pricing to better optimize energy storage assets. To manage this challenge, market policies need to evolve to enable corporate power purchase agreements for storage to contribute to local utility resource adequacy requirements and encourage expanded flexibility, efficiency, and value propositions for facilities.

State and federal incentives can assist industrial customers in deploying storage at scale to enhance grid resiliency and sustainability from behind-the-meter. These incentives to facilitate flexible and mutually beneficial storage assets behind-the-meter can defer fossil fuel plant peaking, resulting in reduced carbon production.

Technical requirements vary widely across the industry on both the manufacturing and utility interconnection sides of energy storage deployment projects. Standardization would help reduce costs and deployment timelines for the projects.

There also is an opportunity to provide resources to aid utilities as they work with energy-intensive facilities. Utilities do not consistently have the processes or resources in key areas (e.g., engineering) that can help streamline the process when working with companies as they construct or retrofit energy-intensive facilities. Each region or utility is relegated to developing their own processes and resources for engaging facility developers. Providing resources and training in best practices can benefit utilities and energy-intensive facilities by positively affecting delivery time and potentially reducing the costs and risks associated with siting, developing, deploying, and operating energy storage assets. Appropriate utility policies also can assist in properly scaling and interconnecting behind-the-meter storage of energy-intensive facilities to best manage grid peaks and operations while enhancing the value of the storage investment by the facility and avoiding unnecessary interconnection cues.

Long-duration storage is particularly valuable to energy-intensive facilities and incentives and pilot projects for long-duration storage should be considered for the facilities.

Additional Comments

EAC received additional comments from industry stakeholders. Selected comments are included below:

- As the Electric Power Research Institute has expressed in the past, historical efforts from DOE prior to the ESGC have seemed to emphasize either early-stage technology development (technical readiness levels [TRLs] 1–4) or very-late-stage technology demonstration (TRLs 8–9). There are very few programs addressing technologies and systems at the TRLs 5–7 stages, which are critical to the development of integrated systems and values that meet basic requirements for performance, safety, reliability, and cost. Leaving this work to be done by private companies with investor funding, absent user participation, has resulted in products that are reported by developers to be TRL 8 or 9, but which when deployed in the field, prove to be at a much lower level of development. It would be advantageous if there was an avenue by which technical experts from DOE and other entities can enumerate the characteristics that a storage system at a certain level of maturity would have to demonstrate, along with the verification methodologies (through qualification testing, modeling, or analysis) that would prove that a system indeed possesses those characteristics in order to help developers meet basic product requirements.

- Progress in the ESGC also seems to be somewhat slow. There have been relatively few funding opportunities that have emerged from this program. The tracks seem oriented toward potential applications for energy storage; however, relatively little effort is being directed to the technologies themselves, particularly in identifying technologies that have a reasonable chance of achieving low costs and developing research approaches that advance those technologies toward commercialization. A program that implements a stage gate approach toward a large field of technologies, providing funding toward technologies as they clearly demonstrate progress toward commercial maturity in terms of safety, reliability, and economics, according to predetermined metrics based on application requirements, may be more advantageous.

- Initially, there was no ability to capture an investment tax credit (ITC) on stand-alone storage (this has been resolved with the Inflation Reduction Act).

- As a not-for-profit co-op, the Kauai Island Utility Cooperative could not take advantage of tax credits (this has been resolved with the Inflation Reduction Act now offering a direct-pay option for both co-ops and public power utilities).

- Minor logistical challenges: BESS containers are very heavy when loaded with batteries, so the cost of ocean freight can be an issue, as well as finding capable transport to the site that avoids bridges which have weight limitations and finally offloading at the site.

- Chemistry issues: A lead-acid battery did not last very long in high-cycle applications (but a lithium-ion battery has proven to do well thus far). A stationary storage market seems to be going to lithium iron phosphate, which should help with past safety and exotic materials issues.

- Lithium-ion costs have driven pricing up recently, making stand-alone storage very costly, even with the now available ITC.

- Lithium-ion BESS lead times are challenging projects everywhere. If I placed an order for a Tesla Megapack today, it would not ship until the third quarter of 2024.

- The most significant reliability issue with BESS to date has been inadequate HVAC. BESS require a stable environment and keeping the temperature and humidity within the desired parameters in a Hawaiian environment can be challenging, especially with the relatively extreme manner in which we dispatch the BESS to control frequency. Of note is that Tesla products use automobile-like radiators and fans, and seem to be more reliable than BESS, which use containers that have side-mounted A/C units.

- Inverters also have had reliability issues: If installed outside, they tend to suck in lots of dirt and moisture, which causes premature component equipment failure. If installed inside, there is the extra cost of the building and the need to deal with additional heat build-up. The bottom line is that the entire industry needs to become more mature and robust with their components to ensure that they are “utility grade,” similar to any conventional power plant.

- Once any grid is close to being dominated by inverter-based resources, BESS inverters should use grid-forming controls instead of legacy grid-following controls, which are currently the standard for most solar photovoltaic resources and BESS to date.

- Inverters should follow IEEE Standard 2800-2022 to ensure high-speed data collection at the inverter level (or at least at the plant level).

- There is a need for more commercially proven, long-duration storage options: flow, gravity, rail, and so forth. It seems that these technologies are continuously stuck in the testing phase.

Recommendations

After a review of DOE's efforts and an extensive investigation of obstacles and challenges facing the energy storage industry, EAC has made the following core recommendations for DOE to prioritize for fiscal years 2023 through 2025:

1. Conduct macro-energy storage analysis.
2. Coordinate with industry to promote efficient markets for energy storage.
3. Support local efforts by states and regulators to remove barriers to facilitate markets and remove disincentives for energy storage.
4. Improve the resilience of critical services by supporting the deployment of energy storage at critical services and interdependent network infrastructure.
5. Increase the resilience of the grid and support customer, critical services, and grid-level resilience by facilitating the bidirectional storage capacity of electrified mobility.
6. Facilitate the cost-effective deployment and interoperability of fixed and mobile storage assets by promoting standards that support consistent best practices among the industry and user groups.
7. Address barriers and develop use cases for the industry and end users to facilitate timely and efficient interconnection and accelerate the integration of storage assets to maintain stability and promote resilience as the grid transitions.

1. Macro-energy storage analysis

DOE should conduct a macro-energy storage analysis to determine the power and duration of energy storage needed and where it is needed. This should be compared with the projected availability to assess whether it satisfies the needs and evaluates the cost associated with the needs. The analysis should include 24/7 capacity, reserve margin, energy, and resilience needs, as well as load growth and distributed storage potential associated with EVs and other electrification loads. The analysis should consider the timeframe for the transition from fossil fuel power generation and assess whether energy storage will be available to ensure a reliable and resilient electric grid throughout the transition. This analysis should be communicated to policymakers and regulators to reduce the risk of becoming overly dependent on energy storage if it is not available on the needed timeline.

2. Market efficiency

DOE should coordinate the development of high-level ownership rules and intrinsic value propositions for energy storage systems. These rules should facilitate investments by utilities, third-party developers, and customers that fairly compensate the storage investments while delivering the multiple technical and market value streams. This coordination will need to involve the Federal Energy Regulatory Commission, National Association of Regulatory Utility Commissioners/state regulators, independent system operators, market developers, third-party developers, and utilities. The goal should be to optimize the use of energy storage to benefit end-use customers while balancing a highly reliable electric grid with reasonable cost and equitable opportunities for ownership.

The value of storage should be based not only on the immediate siting and reliability benefits but also the avoided long-term transmission costs. Flexible rate design and ownership models are required. A change in systems thinking from a central push of power model paradigm to a push/pull network resource model is critical.

3. Market barriers

Many local policymakers are continually advised that long-duration storage technologies are “just around the corner.” It is imperative and productive to redouble efforts to help policymakers, regulators, and utilities understand the critical interdependence of energy storage in facilitating VRE resources, such as wind and solar, and the limitations on how much energy storage and VRE resources can be integrated into a grid without compromising reliability. Federal guidance on best practices and standards for integrating energy storage can assist state regulators in facilitating the highest and best value of energy storage integration and remove regulatory and structural barriers and disincentives.

4. Critical services

Recognition of the interdependencies of electric supply and a wide range of other critical infrastructure services is an important next step in ensuring the resiliency of both the grid and those important services.

DOE can play a leadership role in helping to define those interdependencies and evaluate the potential consequences of a failure of each element in those relationships. With support from the industry, this information can then be used to create potential roadmaps for integrating energy storage to facilitate mutual improvements to key elements for the public good. These roadmaps can then be used to prioritize storage-related improvements to each critical infrastructure that improve the overall interdependent system for the benefit of public safety and the resilience of those services.

5. Mobility

Electrified mobility through EVs and emerging electrification of marine and aviation transportation should be acknowledged and quantified in the macro-energy storage analysis (see recommendation 1). The high value of portable energy has been demonstrated for decades in the form of consumer-scale disposable batteries for cordless tools and devices, which can feasibly exceed $50/kWh, underscoring the exponentially higher feasibility of rechargeable batteries. The high-energy storage capacity of EVs can be relocated, coordinated, and deployed to assist with grid-level peak shifting, load balancing, spinning reserve, and emergency power supply needs to support critical segments of the grid or island to support critical industries, critical services, and home-scale resilience. DOE can assist with removing the regulatory barriers for deploying portable storage assets via electrified mobility.

DOE can play an essential role in removing the barriers to grid-to-vehicle interconnectivity and portability. The industry needs signals and incentives to promote interconnection standards, interoperability capabilities, and control platforms for coordinated control of fleets of mobile storage assets. Department outreach can assist utilities and regulators in recognizing the role of electrified mobility as a potential grid-moderating asset rather than destabilizing the grid by growing the magnitude and timing variability of grid peaks. DOE should lead in ensuring that electrified mobility supports grid stability and contributes to the macro storage needs of the grid and not contribute to peaking magnitude and variability that undermines and competes with fixed storage.

6. Standards development

DOE should play a leadership role in promoting the development of standards for the entire spectrum of the energy storage industry, including the compatibility of communications and controls, regulatory consistency, siting and safety considerations, obsolescence, disposal and recycling, reliability, and cyber and physical security.

The role of standards is particularly crucial in the aggregation and dispatch of fixed storage assets at the grid level during both blue sky (normal) grid operations and dark sky (degraded) grid cases. Standards that support the aggregation of electrified mobile assets can prove to be particularly valuable by leveraging their portability to locate and aggregate to critical sites to enhance resiliency at key grid nodes or critical islanded microgrids.

7. Interconnection and integration issues

DOE can assist in accelerating the deployment of storage assets by promoting a two-pronged approach of showcasing successful use cases and best practices, and by assisting state and federal regulators, end users, and industry in recognizing and confronting the barriers to energy storage integration. The barriers include regulatory rigidity in siting, deploying, operating, and the cost recovery of storage assets; financing storage assets; addressing real and perceived technical readiness deficiencies; and creating visibility with regard to performance characteristics and asset life, including end-of-life repurposing or disposal.

Conclusion

EAC commends DOE for its efforts to create a coordinated strategy around energy storage technology development and deployment through the ESGC. The effort is a significant advancement in ensuring a coordinated federal approach to the development of a critical infrastructure resource for the future.

However, after review of the efforts of the Department to date under the ESGC, as well as extensive investigation with energy storage utility stakeholders, EAC concludes that there is a strategic disconnect between the efforts of DOE and the obstacles and challenges facing the industry, policymakers, and adopters. While the Department has focused extensively on early-stage technology development, primarily around battery chemistry research, to reduce costs, there is a driving need across the country for additional work and support to solve the core business and regulatory challenges with deployment that will exist whether the price per watt is 10 cents or $1.

EAC members have identified three primary gaps that would benefit from intentional federal support:

- Supporting policymakers and regulators in efforts to remove barriers to adoption, showcase successful use cases and best practices to promote feasible deployments, and develop plans that appropriately value and integrate energy storage into energy, resilience, and climate policy.

- Supporting efforts to overcome the technical and practical challenges of interconnecting energy storage systems to the grid or behind-the-meter.

- Focusing on technology development challenges around mid-stage technology development (TRLs 5–7) with regard to improving performance, safety, reliability, and cost outcomes for adopters.

The recommendations included above represent a high-level overview of suggested approaches for tackling the most pressing obstacles and challenges faced by the industry and policymakers in ongoing efforts to accelerate the energy transition.