

PNNL-39335

Energy Storage Siting and Permitting Outreach Workshop Report

May 2026

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Jessica Kerby

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Pacific Northwest National Laboratory
Richland, Washington 99354

Abstract

On March 24th, 2026, under the sponsorship of the U.S. Department of Energy's Office of Electricity, Pacific Northwest National Laboratory (PNNL) staff hosted the *Energy Storage Siting & Permitting Outreach Workshop* at PNNL's Grid Storage Launchpad (GSL) facility in Richland, Washington. The workshop convened a cohort of state and regional stakeholders from across the country to build a shared understanding of energy storage technologies, regulatory frameworks, and best practices for engaging in the permitting process. Participants left with a deeper understanding of energy storage technologies, grid uses and benefits, interconnection and regulatory processes, battery safety standards and risk management, and local engagement strategies and approaches. The workshop concluded with a guided tour of the GSL for hands-on exposure to energy storage research and development. The workshop had 17 external participants. The attendees represented a range of backgrounds, including state and local governments, nonprofits or other local organizations, project developers, and utility stakeholders.

Acknowledgments

This project was funded by the U.S. Department of Energy, Office of Electricity (OE), Energy Storage Division. The authors would also like to acknowledge the incredible work of Alyssa Gorrell, who led communications support for workshop materials, publicity, and outreach, as well as Lara Watkins, who provided invaluable logistical support, ensuring that the event ran smoothly for all participants.

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1.0 Introduction and Overview

On March 24th, 2026, PNNL staff members hosted the one-day Energy Storage Siting and Permitting Outreach Workshop at the Grid Storage Launchpad (GSL) at PNNL's campus in Richland, Washington. The workshop, which was funded by the U.S. Department of Energy (DOE)'s Office of Electricity (OE), brought together 17 invited participants representing a cross-section of organizations working on local and regional energy issues, local and state government planning officials, energy storage developers, and utilities. Its primary goal was to offer accurate and informed perspectives on benefits, impacts, and risk mitigation strategies for energy storage technologies to key stakeholders to help them address common concerns and barriers to energy storage deployment that arise in siting, permitting, and regulatory processes.¹ The workshop was free and PNNL provided travel funding to reduce barriers to participation.

The workshop and associated materials were developed as a response to permitting challenges faced by many proposed grid-scale energy storage projects, with local constituent concerns and opposition often a significant factor driving permitting delays and, in some cases, leading to project cancellations.² The workshop offered participants an opportunity to discuss siting and permitting challenges specific to energy storage projects and build a shared understanding of energy storage technologies, regulatory frameworks, and best practices for engaging in the permitting process. The event also included a tour of GSL's laboratory facilities, providing participants with hands-on exposure to PNNL's cutting-edge work on energy storage research and development.

PNNL was well-positioned to lead this event as a national laboratory with established expertise in energy storage testing and validation, grid integration, and regulatory analysis. The workshop was also aligned with OE's strategic priorities, including enhancing the grid's ability to reliably and affordably meet growing demand and maintaining grid reliability and security, given the role of energy storage as a timely and effective tool to support achieving these goals.³ Energy storage's contributions to reliability, affordability, and accommodation of rapid demand growth were among the topics emphasized throughout the event.

The workshop agenda included the following topics and speakers, which are described further in Section 3 of this report:

- Introductions and opening remarks (Devyn Powell, Energy Policy Analyst, PNNL)
- Energy storage fundamentals (Jessica Kerby, Systems Engineer, PNNL)
- Regulatory and permitting processes for energy storage (Devyn Powell)

¹ "Energy Storage Siting and Permitting Outreach Workshop," Pacific Northwest National Laboratory, March 24, 2026, <https://www.pnnl.gov/projects/energy-storage-siting-and-permitting-outreach/workshop>.

² Jason Dodson and Bernd Grebenstein, "Common Energy Storage Project Deployment Challenges (and How to Avoid Them)," Fluence, November 7, 2023, <https://blog.fluenceenergy.com/common-energy-storage-project-deployment-challenges>; Devyn Powell et al., *Tracking Local Moratoria and Other Key Considerations for Battery Energy Storage Siting* (Pacific Northwest National Laboratory, 2024), https://www.sandia.gov/app/uploads/sites/82/2024/08/PR2024_404_Powell_Devyn_Policy.pdf; Michael Hill, "Fears of Massive Battery Fires Spark Local Opposition to Energy Storage Projects," *Insurance Journal*, October 6, 2025, <https://www.insurancejournal.com/news/national/2025/10/06/842596.htm>.

³ Catherine Jereza, *Office of Electricity Strategic Plan* (U.S. Department of Energy Office of Electricity, 2026), <https://www.energy.gov/oe/office-electricity-strategic-plan>.

- Interconnection and grid integration for energy storage (Karyn Boenker, Electricity Resilience Project Manager, PNNL)
- Energy storage project case studies (Devyn Powell)
- Energy storage safety and risk mitigation strategies (Vilayanur Viswanathan, Chemical Engineer, PNNL)
- Local engagement strategies for energy storage projects (Kendall Parker, Systems Engineer, PNNL)
- Supporting energy storage in siting proceedings (Kendall Parker)
- An overview of PNNL's energy storage research portfolio (Vincent Sprenkle, GSL Director and Energy Storage Strategic Advisor, PNNL)
- A guided tour of the GSL (Vincent Sprenkle and Adam Jivelekas, GSL Director of Operations, PNNL).
- Closing remarks and discussion (Devyn Powell)

In addition to disseminating salient and actionable information to energy storage stakeholders, the workshop also provided an important opportunity for PNNL staff to learn from the wealth of knowledge and experience of the workshop participants to help inform the direction of future work. This knowledge sharing was facilitated in part by the use of *Mentimeter*¹ during three structured discussion sessions: a workshop icebreaker, a working lunch exercise, and a final closing session, to complement the guided discussion throughout the event. Results from these Mentimeter exercises and other discussion takeaways are described more detail throughout this report. All Mentimeter results are included in Appendix A.

¹ Mentimeter is an “interactive audience engagement platform” capable of displaying interactive surveys, quizzes, open-ended questions, and word clouds in real-time as participants in the room respond via web interface. See: <https://www.Mentimeter.com/>

2.0 Workshop participants and outreach

The event was attended by 17 invited participants. Notably, this represented 100% attendance by everyone who RSVP'd to the event. Initial outreach was focused on representatives from organizations who participate in, or support participation in, siting and permitting processes for energy storage projects. Outreach began in 2025 to organizations with existing relationships with PNNL staff from previous work and groups identified as relevant potential attendees or partners based on the focus of their work. Additional organizations were identified for outreach via these initial conversations.

These outreach efforts were intended both to gauge interest in the workshop and to gather input on topics for the workshop and related materials. Echoing discussion themes at the workshop itself, these conversations emphasized the importance of accessible, plain-language resources describing battery safety and risk mitigation, support for stakeholders navigating siting and permitting processes, and clear explanations of the grid benefits of energy storage. Based on input from these initial conversations, the PNNL team developed a collection of factsheets that were shared with workshop participants and published online.¹ The factsheets are also included as Appendix B of this report.

All attendees were either directly invited to the event by PNNL or reached out about the event after learning about it from colleagues or partners. As expected, not all groups who were part of PNNL's original outreach efforts were able to send representatives to the workshop.

The organizations represented by workshop attendees are indicated in [Table 1](#) below.

Table 1: Organizations Represented by Workshop Attendees

Organization
Great Plains Institute
LPE Stragies
CleanTech Alliance
Solar United Neighbors
Greenlight America
Admiral Strategies
Washington State Department of Commerce
Rural Climate Partnership
Skagit Valley Clean Energy Alliance
Town of La Conner Council
Avangrid Power
Tetra Tech

¹ These factsheets are available on PNNL's website. See Pacific Northwest National Laboratory, "Energy Storage Siting and Permitting Outreach Workshop."

Klickitat County, Washington Planning Department

Puget Sound Energy

Copia Power

When asked to describe their sector of work, 44% of the participants identified as representing a nonprofit or community organization, 25% represented state or local governments, 19% were project developers, 6% percent worked for a utility, and 31% of participants identified as “other.” These “other” participants clarified that they either saw themselves as representing a combination of these sector choices or an adjacent category, such as research organization or consultant. The question allowed participants to choose multiple responses.

What sector best represents your work?

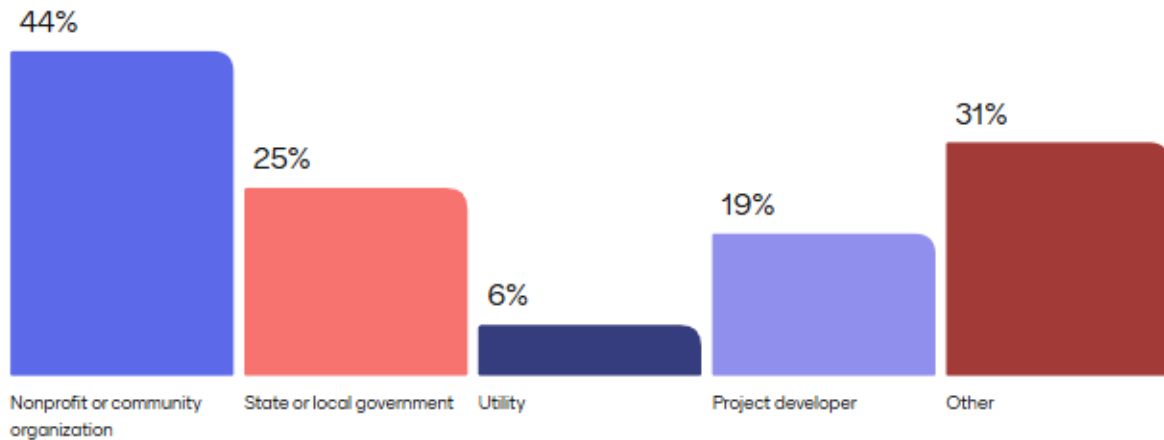


Figure 1. Participant responses to the question, “What sector best represents your work?”

The majority of participants were based in Washington and worked in the Pacific Northwest. However, several were from other states, with these attendees traveling from Minnesota, Colorado, Nevada, and California. Outreach for the workshop was conducted nationally and content was developed to be relevant to stakeholders across the country, but heavy representation from Washington was expected both due to the physical location of the event and greater familiarity with PNNL in the state.



Figure 2. Mentimeter visualization of workshop participant responses to the question “Where are you based?”

When asked to describe their work related to energy storage, in response to a Mentimeter question that allowed participants to make multiple selections, half of the responses described their work as relating to policy or regulation, followed closely by local organizing or advocacy. Additional responses included planning or developing projects, research, and grid integration.

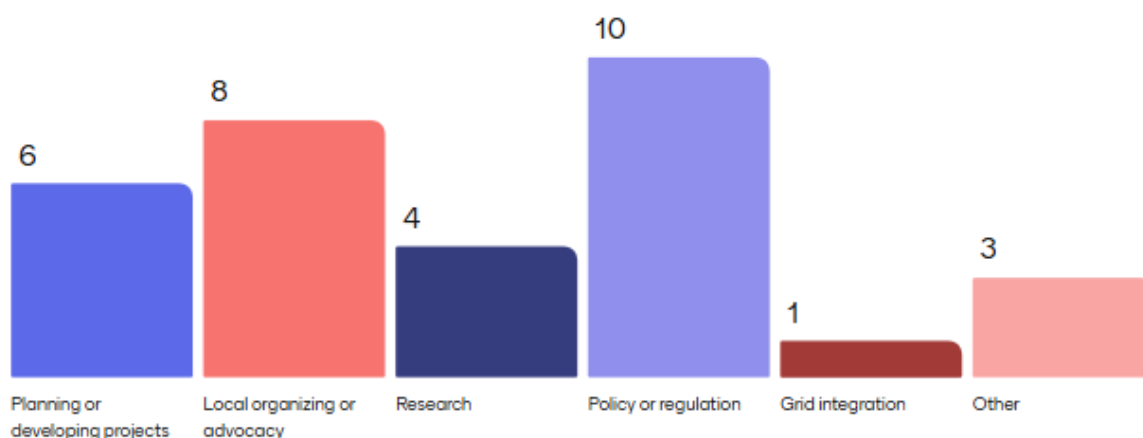
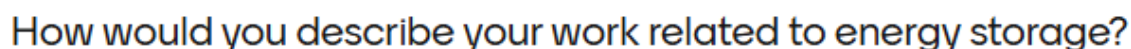


Figure 3. Participant responses to the question, “How would you describe your work related to energy storage?”

The majority of participants responded that they are most familiar or primarily work on large, utility-scale projects, with the other half of respondents nearly evenly split between community- and residential-scale projects.

3.0 Workshop sessions

The workshop was organized into seven session topics, each presented by a PNNL representative with subject matter expertise.

1. **Energy storage fundamentals:** The workshop began with an overview of the fundamentals of energy storage technologies and some of their grid benefits, led by Jessica Kerby. This presentation included descriptions of different battery chemistries and their common applications, with a focus on market-dominant lithium-ion batteries. It also described energy storage applications and their impact on project economic potential, including how storage can contribute to energy arbitrage, ancillary services, transmission and distribution deferral, and demand management.
2. **Regulatory and permitting processes:** The subsequent session focused on some key considerations and challenges for permitting, siting, and regulation of energy storage, led by Devyn Powell. This presentation described permitting pathways and challenges, addressed the rise of local moratoria against energy storage projects, and summarized PNNL research on best practices for including energy storage in local zoning regulations.
3. **Interconnection and grid integration:** The third session was led by Karyn Boenker and introduced the interconnection process for energy storage solutions, including grid integration challenges and emerging solutions. The presentation outlined unique interconnection challenges faced by energy storage projects navigating queues that were designed for generation technologies and discussed grid services that energy storage can provide in additional detail.
4. **Case studies and working lunch:** The working lunch session was a guided discussion of a selection of energy storage case studies, followed by a Mentimeter exercise asking participants what they believed were the most important benefits of energy storage, what concerns and challenges they have seen in their experiences, and what they perceive are the biggest barriers to energy storage deployment. Themes from this and other participant discussions are described more detail in Section 4.0 below.
5. **Safety and risk mitigation:** After lunch, Vilayanur Viswanathan walked through trends in energy storage safety incidents and risk mitigation, highlighting the critical role of energy storage safety standards development and timely standards adoption.
6. **Local engagement strategies:** With safety in mind, the next session, led by Kendall Parker, discussed the value of intentional community engagement strategies to support project success and community acceptance.
7. **Energy storage in siting proceedings:** Finally, best practices in supporting energy storage siting proceedings were presented, also by Kendall Parker, with discussion highlighting the difference between public comments and expert testimony, and the importance of each in informed proceedings.

Vincent Sprenkle, director of the Grid Storage Launchpad, then joined the workshop to provide a brief overview of PNNL's energy storage portfolio and the value of the GSL facility in advancing the energy storage landscape and accelerating the pace of technological advancement. He and Adam Jivelekas then led a guided tour of the GSL, where workshop

participants were able to meet PNNL researchers in their lab spaces to learn about their work and see GSL's prototyping capabilities firsthand.

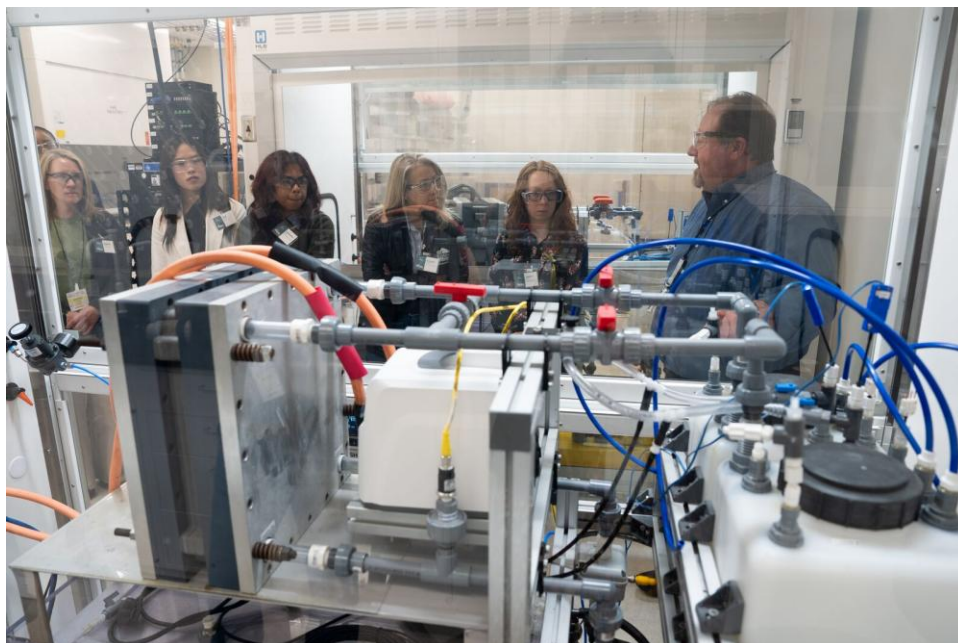


Figure 4. Workshop participants on a guided tour of the GSL.

After the tour, the workshop closed with a final session to recap lessons learned and collect final Mentimeter responses from participants. The exercise captured key takeaways, remaining questions, and suggestions for future resources from workshop participants. Themes and key takeaways from these discussions are described in Section 4 below.

4.0 Emergent Discussion Themes

Over the course of the workshop, through both open discussion and responses to structured discussion questions presented via Mentimeter, some common themes emerged. These included topics that participants were eager to learn more about, common challenges and concerns, and suggestions for future materials or outreach work. The outcomes of these discussions can offer valuable insight to help inform future PNNL and OE work on energy storage, and are summarized below.

4.1 Topics of Interest

- *Operational considerations for specific climates:* Participants were interested in learning more about the additional requirements or specific considerations to keep in mind when siting energy storage in high temperature climates. Specific questions were raised regarding the impact of temperature on battery safety and incidence of failure as well as the impacts on battery operational lifetimes when located in high-temperature climates, such as southern California or the Nevada desert.
- *Battery chemistries:* The energy storage fundamentals session of the workshop introduced basic functions of grid-scale batteries and briefly mentioned a range of different battery technologies. Given the prevalence of lithium-ion batteries, the presentation largely focused on lithium-ion. The session explained that lithium-ion batteries hold the largest market share of commercially available batteries, and provided a brief overview of the various lithium-ion battery chemistries that are commonly used and their typical use cases. Participants sought further detail on how to decide which chemistry is best suited for their project, and greater insight into market trends for each chemistry. Some participants expressed interest in non-lithium-ion chemistries, including practical applications, economic feasibility, and safety tradeoffs as compared to lithium-ion technologies.
- *Safety statistics:* Battery safety was emphasized as the most common concern voiced by community members that workshop attendees encountered in their work. Participants expressed a strong desire to dive deeper into this topic, including interest in learning more about industry trends, the impacts of updated codes and standards adoption, and variation in safety risk between battery chemistries. Specific questions were raised concerning the failure mechanisms that lead to battery fires and trends in failure rates and drivers over time. Participants also expressed interest in additional information and resources to help colleagues, neighbors, and constituents contextualize the scale and severity of safety incidents, such as by comparing storage fires to other, more familiar events, like a house fire.
- *Demand charge reduction and peak load shaving:* Realizing the benefits of energy storage projects at scale often depends on the effective communication of their potential use cases. When participants considered that residential demand charge reduction and peak load shaving on the grid were effectively the same energy storage use case, just at a different scale, the workshop cohort realized that this relationship could be leveraged for effective communication of the benefits of energy storage, specifically in how it can be used to address both modern and emerging grid and customer challenges.

4.2 Common Challenges and Concerns

- *Air and water impacts:* Participants were eager to learn more about the potential impacts to watershed and local air quality in the event of a battery fire. This was highlighted as the

primary concern and reason for opposition to local siting of energy storage projects. Key questions were how to safely divert and dispose of water runoff from fighting battery fires and how the smoke and emissions from a battery fire compares to that from other fire sources, like a house fire or wildfire.

- *Addressing opposition from trusted local voices:* While much of the community engagement discussion highlighted the value of partnering with trusted local voices to facilitate effective dialogue with community members, participants presented a challenge they were facing where their local fire chief was the strongest oppositional voice to a project. This topic was discussed at length, with a few strategies presented both in how to respond to this scenario and how to avoid it in the future.
- *Identifying local partners:* Both project developers and advocates noted that it can be difficult to identify potential local partners to lend support to a proposed project. The “spectrum of support” analogy was presented as a tool to identify and communicate the range of voices that might be encountered during the project development cycle. Participants requested lessons learned on what “good” project development practices looked like, and how to emulate those successful pathways.

4.3 Participant Suggestions for Future Work

- *Communicating the benefits of siting energy storage locally:* There was much discussion on how and which local benefits of an energy storage project are realized based on where it is sited on the grid. Participants raised concerns that some siting decisions may not maximize storage benefits. For example, zoning restrictions that require energy storage projects to be sited in industrial zones may not maximize grid benefits compared to locating the project closer to a substation or on a distribution feeder closer to residents. Conversely, another concern was that community members are often unsure of how the benefits of a grid-scale energy storage project will practically benefit them. Suggestions were offered for resources that effectively communicate local benefits of energy storage, such as lowering energy bills, improving grid reliability, or providing blackstart capabilities.
- *Project success stories:* Workshop participants repeatedly came back to the need for more case studies and success stories and responded favorably to the lunchtime presentation describing case studies of energy projects from previous PNNL publications. The importance of building emotional connection to by illustrating tangible project benefits was raised as one strategy to help navigate local skepticism about energy storage safety or other potential downsides. Participants were interested in more case studies and other resources that could be used to hold productive discussions to help people to see themselves as benefiting from a proposed project as opposed to only fearing potential harms.
- *Contextualize risks against alternatives:* Energy storage projects are generally proposed to solve a real or perceived challenge within a local or regional energy system, such as a need for additional capacity to meet growing peak demand. A recurring conversation at the workshop brought up alternatives to energy storage that would otherwise meet those needs, which led to an interest in comparative resources to help community members evaluate the risks, benefits, and costs of energy storage against other infrastructure. These alternatives may include substation upgrades, new transmission projects, or new generation plants. Some of these alternatives may encounter more local opposition than an energy storage project, or may have other downsides, such as a higher increase in electricity rates to pay for more expensive infrastructure investments.

- *Regulatory mechanisms to maximize affordability benefits of energy storage:* Participants highlighted the uncertainty of available market mechanisms for energy storage compensation, and this uncertainty was named as a potential barrier to energy storage deployment. Some participants also expressed that it was unclear what inputs are used to determine rate tariffs available to energy storage. Where specific rates or enabling regulatory mechanisms do not already exist to maximize the affordability benefits of energy storage, pilot programs were suggested as both a pathway for potential compensation and a source of data to inform regulatory and ratemaking proceedings. Recent PNNL work on the affordability benefits of energy storage¹ was mentioned during these conversations, but additional research exploring various use cases in more detail or resources directed toward specific stakeholders may be of value.
- *End of life considerations:* Some participants requested more information about battery end of life considerations that would be helpful for local planners and their constituents. A factsheet with high-level information about end of life considerations was shared with participants during and after the workshop, but the subject was not explored in detail in the workshop sessions. Questions were also raised about options for battery repurposing or second life applications, including ongoing interest in innovations to help maximize batteries' second-life potential.
- *Additional safety and risk mitigation topics:* Safety remained a topic of high interest to all participants. There was a strong appetite for additional resources that described safety considerations and risk mitigation activities in more detail for a range of audiences, including and especially members of the public with limited technical backgrounds. Participants expressed interest in additional factsheets or white papers, videos, webinars, and case studies exploring safety topics that could be used for public education and other purposes.

¹ Jeremy B. Twitchell et al., *Energy Storage and the Law of Averages: How Storage Can Make Electricity More Affordable* (Pacific Northwest National Laboratory, 2026), <https://www.pnnl.gov/publications/energy-storage-and-law-averages-how-storage-can-make-electricity-more-affordable>.

5.0 Summary and Conclusions

The Energy Storage Siting and Permitting Outreach Workshop hosted by PNNL in March 2026 highlighted PNNL's wide-ranging expertise in energy storage, including regulation, valuation, safety, and research and development. Attendees were largely practitioners working on different aspects of energy storage deployment, including project development, grid planning, and local regulation. The workshop content was focused on addressing topics of interest identified through previous research and initial outreach conversations, which emphasized a growing need for objective, accessible information about the benefits, risks, and general characteristics of energy storage.

Participants offered positive feedback about the workshop, both at the event and in a brief post-event survey.¹ Attendees said they appreciated the knowledge and clarity demonstrated by the PNNL presenters, the scope of topics, and the opportunity for discussion with the presenters and each other. The positive feedback and high levels of engagement with the content throughout the event emphasize the value of continued PNNL investment in educational materials designed to be accessible for non-technical stakeholders, whether through additional workshops, webinars or virtual trainings, factsheets, or other resources.

As energy storage deployment continues to increase nationwide in response to demand growth, economic factors, and needs for investment in grid reliability and resilience, local opposition and permitting delays are likely to also increase without proactive investment in effective training and resources. Building on the success of the workshop and participant suggestions, PNNL is likely well-positioned to continue to develop these resources. Topics of interest include expanded work on battery safety and risk mitigation, affordability and economic benefits, and opportunities to maximize both grid and community benefits of energy storage, among others.

¹ See survey here: <https://forms.cloud.microsoft/g/cL77Hbk28D> Note that as of the time of writing, only five participants had filled out this survey.

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Appendix A: Responses to Structured Discussion Questions

Workshop participants responded to a series of polls and open-ended questions via the Mentimeter platform. The results of those exercises are presented below.

Table 2. Mentimeter responses to welcome exercise

What sector best represents your work?	
Nonprofit or community organization	7
State or local government	4
Utility	1
Project developer	3
Other	5
How would you describe your work related to energy storage?	
Planning or developing projects	6
Local organizing and advocacy	8
Research	4
Policy or regulation	10
Grid Integration	1
Other	3
What scale of energy storage projects are you most familiar with or have primarily worked on?	
Large/utility scale projects	13
Community-scale projects	6
Residential-scale projects	5
Other	1
What is one key question or goal you have for today?	
Fire safety	
How [do] battery technolog[ies] actually work?	
Predicted impacts of BESS on land use	
Explore new approaches to storage	
What are the real fire risks with energy storage systems?	
To find non-biased trusted resources for communities to reference. How to combat fire misinformation?	
Goal: learn more about siting recommendations and/best practices	
To learn as much as possible about battery storage and safety.	
Learn about the most effective ways communities can show up to support the permitting of large-scale projects at hearings.	
Effective public communication about BESS	
Energy storage safety—does thermal runaway destroy surrounding water, air, etc.	
Deeper knowledge on energy storage to help with local advocacy	
Permitting strategies.	
What is the state of art in large scale BESS safety, and what are the best practices in communicating safety to communities?	
Battery performance and safety in climates with higher temps	
Local coordination around fire safety	
How to counter local opposition based on emotions and misinformation.	

Decimal answers in Table 3 reflect participants' ranking of suggested topics from most to least important.

Table 3. Working lunch Mentimeter exercise responses

What do you think are the most important benefits that energy storage can provide?	
Support community resilience	3.9
Improve energy affordability	4.1
Enhance value of generation resources (e.g., firming variable generation)	3.9
Support grid reliability and stability	4.6
Enable flexible interconnection (of generation or load)	3.4
Other	1.3
Think about any specific projects or topics you have worked on or encountered. Have you seen examples of these (or other) concerns or challenges in your work or in your community?	
Concern that if it goes into thermal runaway the town has 6 minutes to evacuate or they will all die ¹	
Yes.	
Not enough knowledge on standards especially for siting.	
Toxins leaking into the soil	
Siting challenges = excessive setback requirements in local ordinances.	
If it goes into thermal runaway the runoff will go into the creek and kill the fish.	
Our rural areas are very resistant to change and this is big new tech.	
Challenges of benefits if BESS being divided by political lines	
Yes. Moratoriums.	
Fire danger, environmental degradation, not consistent with local culture & values.	
Fire concern	
Community fears about fires and environmental impact have resulted in development moratorium.	
Public opinion seems negative, to the point where lawn signs against BESS have appeared.	
Community concerns about fire safety.	
It's too close to a school	
No trust of developers despite having fire experts talk to the community	
Heat concern	
Fear creates moratoriums and unreasonable restrictions	
Yes. We are helping our local schools with 2 large solar plus storage projects and are having problems with both supply chain issues and opposition from our local volunteer fire chief.	
Folks don't have the capacity to address the fire concerns esp[ecially] in rural areas	
Local ordinances – adopting regulations based on oil and gas requirements.	
Challenges for folks who support BESS not being aware of milestones to join the conversation.	
Pollution of water systems from toxic runoff after a fire.	
What are the biggest concerns or questions that you, or members of your community, have about energy storage?	
Fire or other safety concerns	4.8
Impact on local environment or natural resources	4.4
Potential impacts on other land uses (e.g., agriculture, other businesses)	3.6
Nuisance or disruption to area (e.g., noise, viewshed, neighborhood character)	3.8

¹ The participant who provided this response explained during the discussion that this was a real 3.8 misinformation campaign started on social media in their local area.

General unfamiliarity with technologies	4.1
Unsure that benefits outweigh downsides	3.8
Other	1.3
What do you think are the current biggest barriers to deploying energy storage?	
Supply chain constraints	2.9
High project costs	3.3
Interconnection challenges	3.6
Siting or permitting process delays	4.6
Local concerns or opposition	4.9
Other	1.8

The workshop wrap-up exercise collected parting thoughts from participants, including feedback on the workshop and suggestions for next steps, before concluding the event.

Table 4. Metimeter wrap-up exercise responses

What is a key takeaway you have from today?
So much great battery energy storage research happening at this lab!
Better ideas for messaging to communities
BESS fire risk currently is more about components outside the cell than inside the cell
All the great resources that PNNL can provide around Energy Storage
There are lots of PNNL resources for BESS siting & permitting support
Value stacking to communicate about BESS
BESS is essential for the future of our grid – and, it is a safe and viable option for communities with real benefits to resilience and reliability.
PNNL can provide great resources for educating stakeholders around BESS siting and permitting
Grid storage and micro[grid]s are important to overall energy security
I am very impressed with how well organized the presentation was, as well as the entire campus!
BESS safety issues are being addressed via several avenues. Safety issues remain relevant but concerns can be addressed.
Advancement of sodium ion batteries
There is a lot of information about BESS out there that could use additional context
PNNL BESS characterization capabilities
Mitigating 72 hour outages are what the industry is working toward. EFSEC supersedes local government
How a BESS can benefit a grid. The pulsing etc.
Battery storage tech is maturing and safety improving. It's growing in use across US.
We all have different types of storage and finally are able to store energy
The key takeaways from today are the approach on explaining BESS to local communities and a way for easy understanding/comparison to real life examples. ICx was also interesting on the way we study
One of the major goals is the stabilization of the grid
PNNL resources are available to research and document storage concepts.
Explaining what happened in past BESS fires is key for addressing fire concerns.
Battery energy storage is a safe option for providing resiliency and reliability to the grid. Details to back up that statement were learned at this training and networking opportunity.
PNNL has a center of expertise that can benefit the commercial world as well as support advocates in local communities.

What are the biggest energy storage questions you have after today?
What are the risks of other energy systems vs BESS?
How can data center fluctuations impact the grid and ratepayers without BESS? Who is the standards adoption onus on? Developer or regulator?
Not at the moment but appreciate all the great information provided.
How to invite PNNL to present at my org?
More detail on fire smoke and water plume risks to neighbors at BESS sites
Better understanding of water runoff issues.
The most effective messages to combat the different types of concerns about BESS
In case there is a thermal runaway, how will we plan to avoid groundwater and soil contamination?
Where is electric storage going? What technologies other than batteries are close to, or have recently achieved, commercial success? When can we expect the next generation of batteries?
Who is the onus of standard adoption on? Regulator or developer?
How market structures will evolve to properly compensate long-duration storage for the reliability value it provides? How will interconnection processes adapt to new storage operating profiles?
How to mount an education campaign in our community that is credible and believable. How do we become a trusted resource on BESS.
How do you quantify the cost of inaction or not building storage projects?
There is scarcity of LFS right now. Is that correct?
BESS affordability metrics?
How can we better mitigate environmental hazards resulting from BESS fires?
What will this situation look like in five years? Will we be over the major challenges with opposition? Will the scale up have happened? We will be talking about different batteries ?
Does PNNL also research thermal storage, and advanced electric storage concepts like gravity storage?
Can you help us (local non-profit) with our educational outreach?
When will the market move on from LFP? What constitutes an overbuild out if longer duration flow batteries are on the way?
Localized story telling about BESS successes and explanations re fires
BESS co-location with other types of emerging technologies - fusion, SMRs, hydrogen. What cases can it be most effective for?
Will you be sharing attendee list and contact info?
Breakdown of the standards for community members Resource on bottlenecks to BESS development - ie: decision making points that communities can plug in to
What topics would you like to see in future PNNL resources?
I'd like to hear about your wildfire program.
Thermal storage and electric storage other than batteries and pumped hydro. New battery technologies.
Resource on standards for BESS that's accessible for [communities]
Percentage of Lithium types batteries in the industry right now
Data center development best practices
Videos about BESS tech, issues, benefits.
How does BESS colocated with solar differ from BESS stand alone projects?
Points in BESS development processes that communities can plug into? Ie: county vote or state level permitting process
Video presentations in a library format related to the topics presented today might be good
More on successful deployments like the case studies

District heating, thermal energy storage, closed-loop geothermal...	
Seconding the data centers and storage co-location opportunities	
Model projections on various regions of WA as to energy availability and projected shortages. How BESS could change the projections.	
Where are we at with recycling BESS cells? How far away are we from a closed loop lithium battery system?	
What types of resources or training would you find most valuable from PNNL in the future?	
Future in-person workshops	4.3
Webinars or virtual workshops	4.4
In-depth publications about specific topics	4.2
Factsheets and other digestible resources	4.9
Dedicated technical assistance	4.3

Appendix B: Workshop Factsheets

The following factsheets, which summarize PNNL research on various energy storage topics, were disseminated in print to attendees and were also published online on the project website after the event.¹

¹ <https://www.pnnl.gov/projects/energy-storage-siting-and-permitting-outreach/workshop>

ENERGY STORAGE FUNDAMENTALS

This factsheet presents an overview of the fundamentals of energy storage and best practices for energy storage systems, or large stationary batteries installed in residential, commercial, and industrial settings.

KEY TAKEAWAYS

 Value Stacking	Value Stacking involves designing an energy storage system to provide multiple services, such as resilience or backup power, improved grid reliability, utility bill optimization and cost savings, and the opportunity to participate in the energy market. Maximizing the utilization of a battery ensures that the potential benefits of the project are maximized.
 Operating Profile	Configuring the battery's operating profile, or charge/discharge strategy, to provide multiple services requires operational flexibility and forecasting of extreme weather events, utility rate tariffs, and market conditions.
 Critical Loads	Identifying priority or critical loads can help extend the battery's ability to survive an extended outage by switching off, or "shedding", non-critical loads. This can be achieved manually or via a critical loads panel installed with the battery system.
 Energy Markets	The ability for a battery to participate in local or regional energy markets depends on state and federal regulations, where the battery is located, and whether it is in a residential, commercial, or industrial setting.
 Calendar and Cycle Life	When designing and operating a battery system, it is important to keep in mind that batteries have both a calendar life and a cycle life. The calendar life refers to the expected lifetime of the battery due to the aging of its components over time. The cycle life is the number of charge/discharge cycles the battery is expected to achieve before its capacity falls below usable levels.

VALUE STACKING

Battery energy storage can serve many purposes depending on where it is located, its size, and the local electricity market. When planning a project, it is important to consider how and when the system will be used, and whether there are **opportunities for the system to serve multiple uses**—referred to as **value stacking**. For example, a battery project designed to only be used when the electric grid experiences an outage may come at tremendous cost due to low utilization if outages are infrequent. A battery system can be designed to provide support during outages as well as lower monthly electric bills, especially if connected to local generation, or if the building is under a time-of-use (TOU) rate tariff. Under a TOU tariff, the battery would discharge electricity to the building at high or peak prices and charge at low or off-peak prices;¹ batteries can also be used to reduce peak demand, providing demand charge reduction—all while holding some portion of its capacity in reserve in case of an outage.

OPERATING PROFILE

Multiple services are achievable if the **battery operating profile** is configured for both resilience and to reduce utility bills. This typically involves deciding how much of the battery's capacity to elect for each service. For example, if outages were relatively rare and no more than a few hours long, it might make sense to set 70 percent of the battery's capacity for bill management, and 30 percent for reserve in case of an outage. These settings can be adjusted as needed, and many battery management systems are equipped with a weather forecasting feature or are configured to receive alerts from the utility ahead of scheduled outage events or maintenance. In these cases, the battery would be fully charged ahead of the event and hold off on performing utility bill optimization services until the event passed. The outcome of these configurations ensures that the full resilience capacity of the battery is available to support the building tenants. This kind of battery operation is often described as “blue sky” under normal conditions, and “black sky” under emergency or extreme weather conditions.

Under black sky conditions or an emergency scenario, it is important to take preparatory steps to maximize the duration the battery can support its connected load. In most cases, the length of an outage is unknown, though the utility may provide updates and estimates as they perform

the necessary work to restore electric service. Regardless, prioritizing loads to support in an outage will extend the time those loads are able to be met by the batteries. **The loads determined to be a priority are called critical loads and should be identified when the battery is first put into service to best prepare for a resilience scenario.**

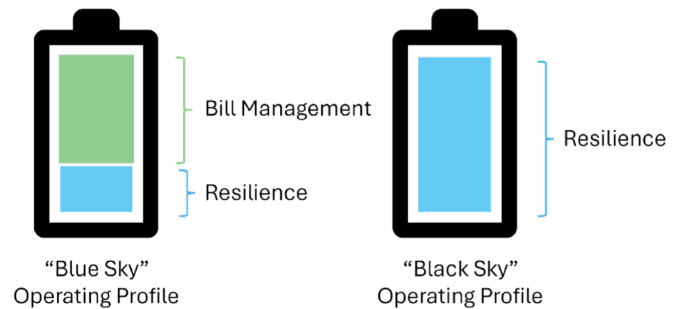


Figure 1. Battery operating profiles for everyday “Blue Sky” conditions (left) compared to emergency “Black Sky” events (right).

CRITICAL LOADS

There are two ways to manage critical loads in an outage, the first is to do it manually. By turning off non-essential appliances and lighting, the battery can provide prologued electric supply to essential equipment like refrigeration. The other option is to manage critical loads automatically using a critical loads panel. A **critical loads panel ensures that the connected battery only supplies electricity to priority loads during an outage**; this contingency management practice can be referred to as **load shedding**, which is a **strategy to help the battery last longer by only providing electricity for the most important uses in the building**. A critical loads panel can either be integrated with the building's electric panel or installed as a separate device. During installation, the electrician will work with the building owner to identify these priority or critical loads. Often, these loads include the refrigerator, critical equipment, minimal heating and cooling, and lighting and outlets to a select few rooms where people will gather or critical services are performed during an outage.

MARKET PARTICIPATION

The potential services that a battery can provide will depend on its size relative to the load it is designed to support, and whether it is combined with an onsite generating resource. It is important to note that battery charging and discharging are not perfectly efficient, meaning that a small percentage of the electricity transferred to or from a battery will be lost, resulting in a slight increase in overall electric demand. There are also market and regulatory factors that determine what battery services can receive compensation. For example, in many jurisdictions, customer-owned batteries are not allowed to export electricity to the grid. This means that the battery can only offset the load of its building and cannot receive compensation for any excess electricity available to export the grid. Where batteries are able to export to the grid, they may also be able to provide **ancillary services to the utility, such as frequency and voltage support**. Larger, commercial and utility-scale batteries can even provide **bulk energy services** to the local grid, **such as capacity support and resource adequacy**; helping ensure that sufficient electricity is available to meet demand during periods of peak use or system stress. The landscape of possibilities for energy storage market participation is constantly changing, and the recently passed FERC Order 2222² is intended to enable distributed energy resources like energy storage to participate in electricity markets. Similarly, FERC Orders 2023a and 2023-A³ strive to ensure that energy storage resources are more accurately studied during the interconnection process to avoid unnecessary, costly, and time-consuming network upgrades.

BATTERY LIFETIME

The operating profile, or the way in which the battery is operated, will impact the lifetime of the battery. Batteries have a **calendar life**, or the **expected lifetime of the battery due to the aging of the battery's components with passage of time**. Batteries also have a **cycle life**, or **the number of charge/discharge cycles the battery is expected to achieve before its capacity falls below usable levels**⁴. The estimated cycle life is complicated by the fact that a battery is not always fully discharged and charged every cycle. **When a battery is only discharged slightly before being charged**, it is called **shallow cycling**, which usually does not impact the battery life as much as a full cycle. **The extent to which a battery is used before being charged** is called the **depth of discharge** and is an important consideration for an operating profile. Not all batteries respond the same way to these operating considerations, and this response depends on the battery's chemistry. Lithium-ion batteries make up the majority of energy storage chemistries for stationary batteries and electric vehicles, while lead-acid batteries have traditionally been used as combustion-engine car batteries. There are many different battery chemistries with different benefits and drawbacks. For example, lithium iron phosphate (LFP) batteries tend to have higher cycle life and stability, but lower energy. Nickel, manganese, and cobalt (NMC) batteries, on the other hand, tend to have higher power and capacity, but are considered less stable. Lithium manganese oxide (LMO), lithium cobalt oxide (LCO), and nickel, cobalt, alumina (NCA) are other common battery chemistries one might encounter.

The conditions and factors that increase efficiency, calendar life, cycle life, operating temperatures, and safety are regularly studied. The goal of evaluating these conditions is to reduce costs and improve the efficient use of battery materials⁵.

¹ Charging (buying energy) at low prices and discharging (selling energy) at high prices is called energy arbitrage.

² See FERC Order No. 2222 Explainer: Facilitating Participation in Electricity Markets by Distributed Energy Resources.
<https://www.ferc.gov/ferc-order-no-2222-explainer-facilitating-participation-electricity-markets-distributed-energy>.

³ See Final Rules Establishing and Revising Standard Interconnection Agreements and Procedures for Large Generators.
<https://www.ferc.gov/electric-transmission/generator-interconnection/final-rules-establishing-and-revising-standard>.

⁴ Note that the acceptable degradation in battery capacity depends on the battery's application. For example, electric vehicle batteries are typically replaced when their capacity has been reduced to 80 percent of the original value. Battery recycling programs help ensure that these batteries continue to be useful in a second life application, such as a stationary backup or paired with solar or wind generation. After the second life, batteries are recycled, the raw materials are extracted, and any hazardous materials are disposed of appropriately.

⁵ For more information on the different types of battery chemistries, how they work, and how they can benefit the grid, see the PNNL Explainer Article: www.pnnl.gov/explainer-articles/types-batteries

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BENEFITS OF ENERGY STORAGE

This factsheet presents an overview of the benefits of energy storage systems, or large stationary batteries installed in residential, commercial, and industrial settings.

KEY TAKEAWAYS

 Access	Energy storage can provide access to on-demand electricity . When paired with locally generated electricity, energy storage can support energy independence.
 Affordability	Energy storage can reduce the cost of electricity by storing low-cost, off-peak or locally generated electricity for use during high-cost, peak electricity price periods, supporting time-of-use bill management and reducing demand charges.
 Improved Air Quality	Energy storage can reduce the need for backup diesel generators, improving local air quality during an outage . Energy storage paired with generators that do not require purchased fuel can reduce the emissions impact of local electricity demand without sacrificing grid reliability.
 Resilience	Energy storage provides resilience to grid outages , whether the result of local grid conditions, extreme weather events, or utility-initiated shutoffs by providing uninterrupted access to electricity for critical infrastructure, such as hospitals and community gathering spaces.
 Social Impact	Energy storage paired with local generation sources can serve as a community asset, not only providing energy independence, but community ownership and wealth creation.

ENERGY ACCESS

Traditionally, much of the electric grid has relied on large fossil fuel powered generators that operate at any time of day, so long as they have enough fuel. Today's electric grid has many more generators that are distributed throughout the grid, and many of them are powered by variable energy sources like the sun and wind, whose fuel supply is not consistently available. These resources vary with the time of day, weather, or season. To ensure that electricity demand can always be met, a diverse mix of generators can be combined with energy storage to overcome fluctuations in available energy generation.

Electricity moves through the grid nearly instantaneously, so supply and demand must be balanced in real time. If electricity is generated when there is not enough demand, or not enough people are using electricity, some generation must be curtailed, meaning that the potential energy production is reduced or unused. Energy storage devices, such as residential, commercial, and industrial-scale batteries, store this excess energy for later use, increasing access to generated electricity.

Energy storage can also help bring electricity to places off the grid. At the smaller scale, a portable battery and a deployable generating device are great for camping or keeping devices charged during a small power outage. Scaling up, a small home could get most of the power it needs from a rooftop system paired with a small residential battery. At larger scales, batteries can be paired with irrigation systems in remote areas or farms where there may not be a nearby power line. These systems provide electricity at locations where there was no previous access and can provide considerable cost savings compared to utility-purchased electricity. Freight-sized energy storage systems can serve communities, commercial, and industrial processes at even larger scales.

RESILIENCE

Like nearly every critical resource such as food and water, the ability to store electricity brings resilience to the electric grid. Energy storage solutions provide this resilience by supplying access to energy during power outages. In turn, this added resilience helps to keep essential services like hospitals and emergency shelters running and prevents refrigerated food and medicine from spoiling.

SOCIAL IMPACT

Resilience hubs are community centers, libraries, shelters, schools, or other public places that are equipped with energy storage systems designed to serve the public and boost community resilience. In an outage or emergency, these resilience hubs are a place to safely gather, receive information and updates, coordinate response and relief efforts, charge phones and medical devices, and even distribute supplies and first aid. Energy storage enables resilience hubs to better serve their communities in times of need.

ENERGY AFFORDABILITY

Energy storage can also provide cost saving opportunities and increase energy affordability. Many electric utility companies offer or even require their customers to be on time-varying rate tariffs, such as a time-of-use (TOU) rate structure. These tariffs are designed to better reflect the real cost of energy throughout the day. On most summer days, electricity is most expensive in the early evening hours as solar generation drops off, air conditioning use is high, and households require more electricity for cooking and entertainment. These high-demand times are represented by elevated electricity prices, signaling an opportunity to rely on stored electricity or delay chores like laundry, running the dishwasher, and charging electric vehicles (EVs) to times when the demand and price of electricity is lower.

Energy storage can help replace high-cost utility electricity during peak prices. Electricity that was stored earlier in the day, either generated locally or charged from the utility during off-peak pricing, can be used during these high-cost peak times to reduce electric utility bills. Pairing energy storage with on-site generation is an effective way to reduce electric utility bills, as generated electricity can be used to power a house not just during the day, but throughout the night using a battery. This operational strategy is depicted in Figure 1.

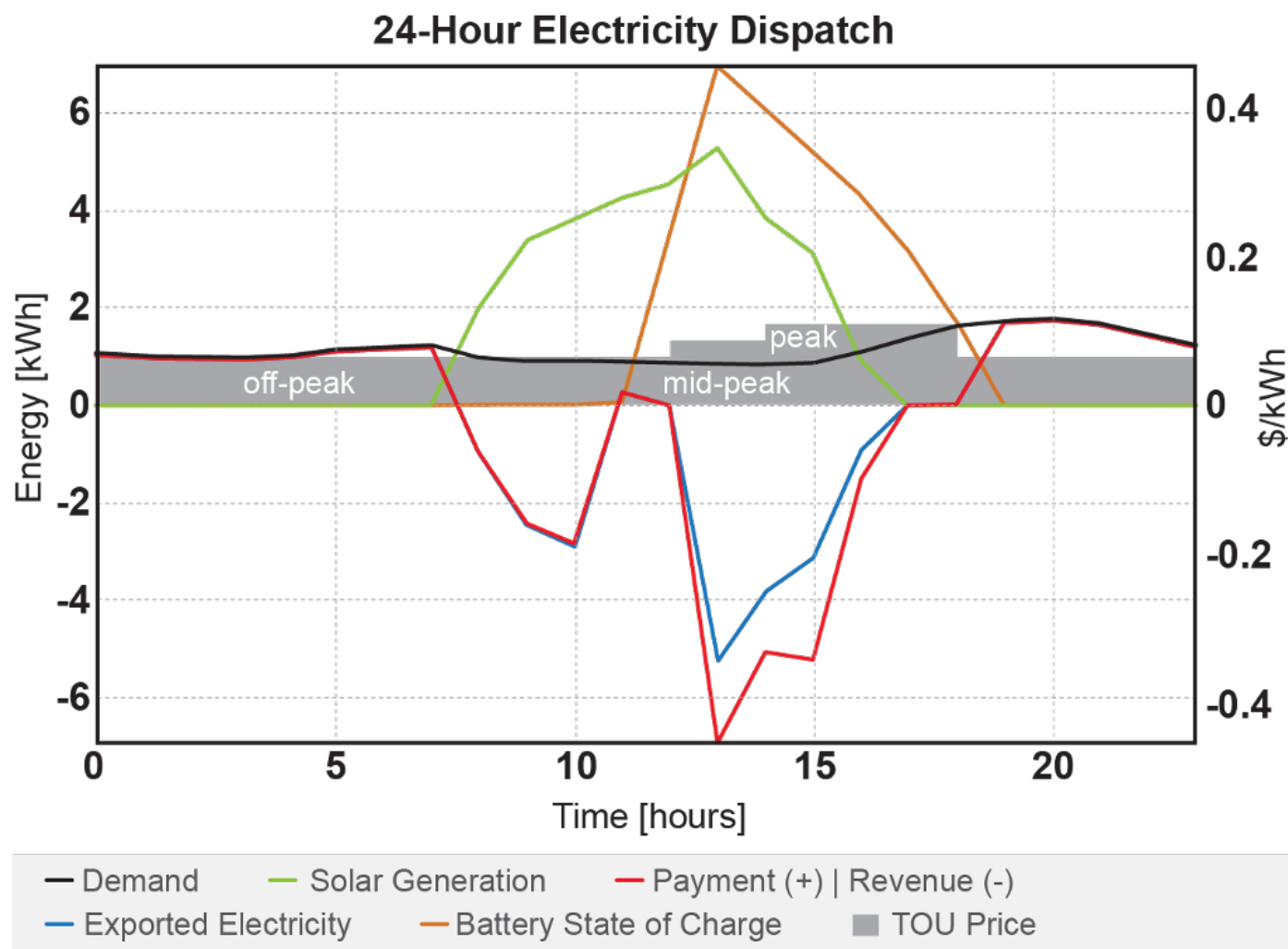


Figure 1. Electricity generated or stored can reduce energy bills when used during peak electricity prices, as shown in this 24-hour electricity dispatch profile from a home with a solar rooftop system and energy storage.

ENVIRONMENTAL IMPACT

Using energy storage during times of high electric demand can also benefit the environment and improve local air quality. One of the reasons that electricity is more expensive during peak time periods is because the high electricity demand requires utilities to call on the least operationally cost effective generators on the system. These are often called “peaker plants,” and may require more expensive fuels, operate at lower efficiencies, and emit more pollutants than typical generators. As more peaker plants turn on, local air quality can get worse and can even lead to smog alerts on hot summer days. The need for peaker plants decreases when enough households and businesses reduce their demand by using their batteries or avoiding high-demand uses during peak hours and when the utility meets the extra demand with their grid-scale energy storage systems.

The benefits of energy storage extend beyond stationary applications. Electric vehicles act as mobile batteries, storing electricity for fuel as opposed to diesel or gasoline. Transportation is one of the main sources of air pollution¹, and replacing combustion engine vehicles with electric vehicles can improve local air quality. Communities located close to highways and high-congestion areas typically have worse air quality and higher rates of asthma and other respiratory conditions. EVs do not produce tailpipe emissions, meaning that even in heavy traffic or when idling, they do not contribute to local air pollution. The regenerative braking systems used by EVs also reduce wear and brake dust emissions by 80 percent compared to traditional brakes². EVs not only reduce tailpipe and braking emissions, but can also integrate with the grid through vehicle-to-grid (V2G) technologies, providing additional storage capacity to help meet peak electricity demand.

ENERGY STORAGE BARRIERS

While this factsheet has outlined numerous benefits of energy storage, it is important to recognize some of the barriers to adoption. The upfront cost of many energy storage technologies can be burdensome for some project proponents. Depending on the capacity of the battery, the system's physical footprint can also be a limitation. The proposed project's location may not have adequate space that meets siting and safety requirements without increasing the setback distance from property lines or adding fencing or visual screening. Community buy-in and support is also key to a project's success, and local opinions on energy storage vary. Not every proposed project receives support from

the community; outreach may be necessary to communicate the project's benefits and risks with those community members. In response to public safety concerns, some local governments have even adopted temporary moratoria on energy storage projects to provide the time necessary to develop or update local zoning ordinances. The Department of Energy and national laboratories execute technical assistance programs with states, territories, local governments, utilities, and communities that are designed to help these entities understand the benefits and challenges associated with energy storage.

¹ U.S. Energy Information Administration. "U.S. Energy-Related Carbon Dioxide Emissions, 2024." May, 2025. Washington, DC. https://www.eia.gov/environment/emissions/carbon/pdf/2024_emissions_report_final.pdf.

² EIT Urban Mobility. "Study on Non-Exhaust Emissions in Road Transport". May, 2025. <https://www.eiturbanmobility.eu/wp-content/uploads/2025/05/41-EIT-Emissions-Report-5a-Digital-1.pdf>.

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TECHNOLOGICAL PROGRESS IN BESS

This factsheet presents an overview of recent progress in battery energy storage systems (BESS) technology, including improvements in performance, size and cost, software and controls, manufacturing, and safety.

KEY TAKEAWAYS

Area of Progress	Then (2010s)	Now (2020s)	Why it Matters
 Performance	Low energy density, slow response time, limited discharge duration, low efficiency	Improved energy density, faster response times, longer discharge duration, higher efficiency	Reduces cost by increasing lifetime output and grid service capacity, enabling more grid support
 Size & Cost	Pilots (1–5 MW, 1 hour duration), ~\$1,000/kWh battery costs	Large utility-scale systems (20–100+ MW, 3 hour duration), ~\$100/kWh	Increased size and lower costs make BESS more affordable and practical as a core grid asset
 Software & Controls	Basic state of charge monitoring	Advanced energy management with state-of-charge and state-of-health monitoring	Better controls optimize BESS operation and extend system life
 Manufacturing	Limited scale, fragile supply chains	Gigafactories, manufacturing standardization, established supply chains	Improved manufacturing increases quality, consistency, and production efficiency leading to lower cost and faster deployment
 Safety	Limited standards, higher operational uncertainty and risk	Standards developed: UL 9540A, NFPA 855; better monitoring	Improved community and responder safety

PERFORMANCE

Advancements in BESS have led to performance improvements across multiple dimensions. Modern systems exhibit longer cycle life, with lithium-ion chemistries now commonly achieving several thousand full charge–discharge cycles¹. This reduces replacement frequency and lifecycle costs. Energy density has also nearly doubled in the last 20 years², meaning more energy can be stored within a smaller physical footprint with lower weight (Figure 1). This improvement is especially beneficial when there are physical space constraints for BESS. Response times have also improved to the order of milliseconds to seconds, making them well suited for grid services such as frequency regulation, voltage support, and contingency response³. In addition, round-trip efficiency has improved, with most commercial lithium-ion systems now achieving approximately 85–95% efficiency⁴, meaning that only a small fraction of energy is lost during charging and discharging. High efficiency improves operational economics and overall system performance. Finally, the BESS market is expanding to longer duration storage options (i.e., 4–8+ hours, compared to common 2–4 hour systems)⁵. This is made possible through advances in lithium-ion system design and the emergence of alternative chemistries.

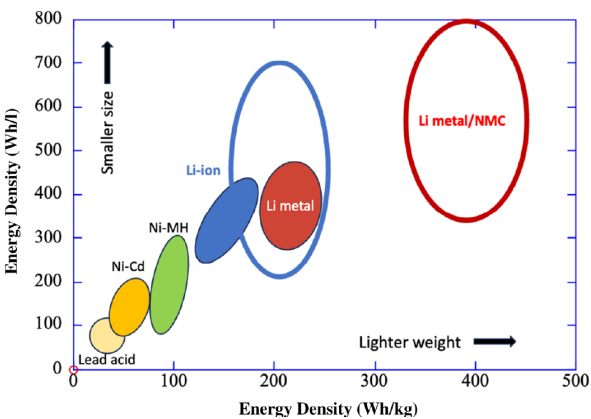


Figure 1. Comparison of battery energy densities in 2001 (closed circles) with commercial cells in 2023 (open circles)².

SIZE AND COST

Over the last decade, BESS has transitioned from experimental, small-scale pilot projects to core grid assets. This evolution is reflected in both the scale of deployments and the rapid decline in costs.

In the early 2010s, grid-connected BESS were typically limited to small demonstration projects on the order of 1–5 MW with 1 hour duration⁶. At that time, battery costs were prohibitively high, around \$1,000 per kWh, which constrained deployment to research pilots and niche applications^{7,8}. By the mid to late 2010s, BESS began to scale rapidly, with utility-scale systems in the 20–100+ MW range becoming increasingly common. This growth was driven largely by cost reductions stemming from the expansion of electric vehicle (EV) battery manufacturing, improvements in supply chains, and learning by doing across the industry⁹. By the 2020s, installations frequently exceeded 100–300 +MW with 3 hour duration with costs falling to a fraction of early deployments¹⁰. Figure 2 shows the historical decline in direct current (DC) Li ion battery cell and pack costs, which are now the lowest-cost high-energy-density battery available. The price dropped from roughly \$917/kWh in 2011 to around \$100/kWh by the early 2020s, with continued cost reductions projected through 2030.

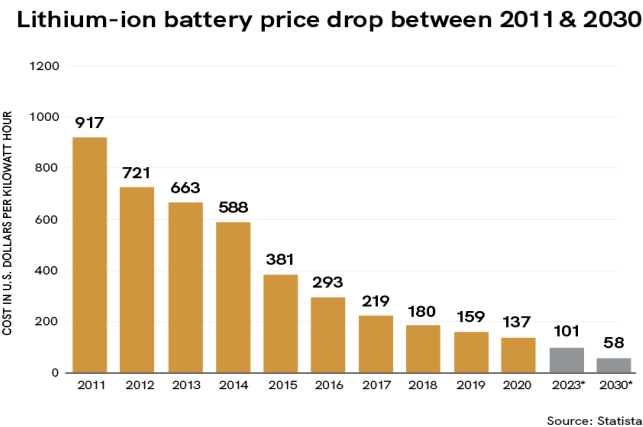


Figure 2. Historical and projected lithium-ion battery cell and pack (direct current) costs. Values exclude power electronics, balance-of-system components, and installation costs⁷.

SOFTWARE AND CONTROLS

Early BESS typically relied primarily on basic charge and discharge control, limiting their functionality to simple energy shifting and backup applications¹¹. In contrast, modern BESS are equipped with advanced energy management systems (EMS) and control software, enabling them to operate as flexible, multi-service grid assets. These EMS platforms allow BESS to provide frequency regulation, fast frequency response, renewable generation smoothing, and participation in wholesale and retail electricity markets through automated dispatch and optimization¹¹. Advanced software also supports continuous BESS state-of-health monitoring, improving visibility into battery degradation and performance over time to reduce downtime and extend system life¹¹.

MANUFACTURING

Manufacturing advances have played a major role in improving BESS affordability, reliability, and scalability. The expansion of large-scale battery manufacturing facilities (“gigafactories”) has driven down costs and improved quality control but increased the need for recycling².

At the same time, the battery industry has increasingly focused on diversifying supply chains for key materials such as lithium, nickel, cobalt, and graphite. Sourcing these materials is not currently sustainable, though material diversification has helped reduce supply risks and improve long-term availability for grid-scale storage deployments².

There is also growing emphasis on battery recycling and second-life applications, where batteries originally used in EVs are repurposed for stationary energy storage². Recycling initiatives aim to recover valuable materials and reduce environmental impacts, while second-life batteries offer a lower-cost option for certain community and grid-support applications.

SAFETY

Early BESS installations often relied on limited monitoring, relatively simple thermal management systems, and lacked standardized fire testing protocols¹². These limitations contributed to greater uncertainty around thermal runaway and provided fewer tools to first responders and operators to detect and manage failure events. In addition, the codes and standards landscape prior to 2019

primarily covered portable consumer cells and battery packs rather than large, grid-scale BESS¹³. As deployment accelerated between 2017 and 2022, safety incidents also increased. This led to heightened awareness of potential hazards, spurring the development of improved codes, standards, and mitigation measures¹³.

Modern BESS designs now incorporate battery management systems (BMS) that continuously monitor battery state of charge and state of health. BMS monitors temperature, voltage, and current at the cell and module level to enable early fault detection and controlled shutdowns¹². These protections operate within broader system controls completed by the EMS. Also, improved cell-level thermal isolation, gas detection systems and enhanced container venting further reduce the likelihood that a single cell failure escalates into a larger event¹². As a result, BESS failure incidents have decreased since 2020 (Figure 3).

In parallel, standardized safety testing and codes have lowered safety risk by strengthening system design and emergency preparedness. UL 9540 establishes system-level safety requirements for BESS. UL 9540A provides a test method conducted in support of UL 9540 certification that evaluates thermal runaway characteristics and fire propagation behavior at cell, module, unit, and installation levels. In addition, NFPA 855 establishes requirements for siting, spacing, ventilation, and coordination with fire authorities to support safe deployment and effective emergency response¹³.

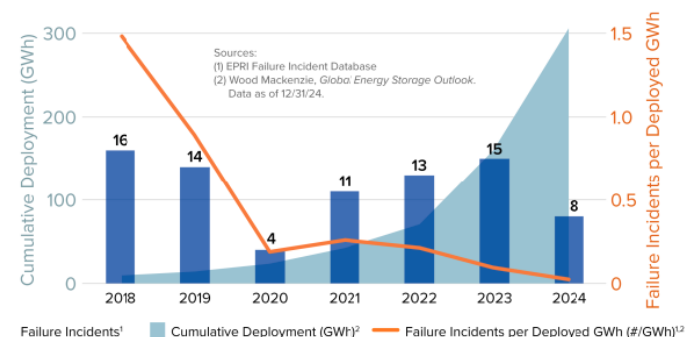


Figure 3. Failure statistics for global grid-scale battery deployment. The numbers on top of the bars are number of failure incidents. The orange line pairs with the right vertical axis. The distribution pairs with the left vertical axis¹⁴.

MODERN BESS BATTERY CHEMISTRIES^{1,2,3,4}

This table summarizes performance, cost, and safety characteristics of some modern battery chemistries present in the market today.

Technology	Pros	Cons
Lithium Iron Phosphate (LFP)	• Very safe and thermally stable • Long cycle life • Lower cost (no nickel/cobalt) • Most common for stationary storage today • High efficiency	• Lower energy density than NMC/NCA(nickel manganese cobalt/nickel cobalt aluminum) • Larger footprint per kWh
Nickel Manganese Cobalt/ Nickel Cobalt Aluminum (NMC/NCA)	• Higher energy density • Used in EVs and some large BESS • High efficiency	• Higher fire risk if damaged • More expensive metals (nickel, cobalt) • Stricter thermal management needed
Flow (e.g., Vanadium Redox, Zinc-Bromine)	• Very long lifespan (10,000+ cycles) • Easy to scale energy (just add more electrolyte tanks) • Non-flammable chemistries • Good for long-duration storage	• Lower round-trip efficiency • Larger footprint • Higher upfront capital cost • Limited commercial track record compared to Li-ion
Sodium-Ion	• Emerging alternative to lithium • Lower cost materials, abundant resources • Good safety profile • Performs well in cold climates	• Lower energy density (larger installations) • Only beginning to scale commercially
Lead-Acid & Advanced Lead	• Very mature technology • Simple recycling processes • Low upfront costs	• Low cycle life compared to modern chemistry • Lower energy density • Poor performance under deep cycling

OTHER TECHNOLOGIES NOT YET COMMERCIALY AVAILABLE

- Solid-state lithium – Higher safety and density
- Metal-air batteries (zinc-air, aluminum-air) – High energy density
- Thermal storage systems (molten salt, thermal batteries) – non-battery alternatives

¹ Pan, Lee. 2025. "Lithium Polymer and Lithium-Ion Battery Lifespan Comparison 2025." Large Battery, March 12, 2025. <https://www.large-battery.com/blog/lithium-polymer-battery-lifespan-vs-lithium-ion/>.

² Whittingham, M. Stanley, and Jie Xiao. 2023. "Fifty Years of Lithium-Ion Batteries and What Is Next?" *MRS Bulletin* 48 (11): 1-7. <https://doi.org/10.1557/s43577-023-00627-z>.

³ Sakib, Sadnan, Md. Biplob Hossain, Muhammad Ahsan Zamee, M. J. Hossain, and Md. Ahasan Habib. 2025. "Role of Battery Energy Storage Systems: A Comprehensive Review on Renewable Energy Zones Integration in Weak Transmission Networks." *Journal of Energy Storage* 128: 117223. <https://doi.org/10.1016/j.est.2025.117223>.

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<https://www.statista.com/statistics/883118/global-lithium-ion-battery-pack-costs/>.

⁸ Trahey, Lynn, Fikile R. Brushett, and Nitash P. Balsara et al. 2020. "Energy Storage Emerging: A Perspective from the Joint Center for Energy Storage Research." *Proceedings of the National Academy of Sciences* 117 (23): 12550-12557. <https://doi.org/10.1073/pnas.1821672117>.

⁹ National Rural Electric Cooperative Association. 2020. *Battery Energy Storage Overview Report: Update*. Arlington, VA: National Rural Electric Cooperative Association. May 2020. <https://www.cooperative.com/programs-services/bts/Documents/Reports/Battery-Energy-Storage-Overview-Report-Update-May-2020.pdf>.

¹⁰ Viswanathan, Vilayanur, Kendall Mongird, Ryan Franks, Xiaolin Li, Vincent Sprenkle, and Richard Baxter. 2022. 2022 Grid Energy Storage Technology Cost and Performance Assessment. PNNL-33283. Richland, WA: Pacific Northwest National Laboratory.

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¹⁴ U.S. Environmental Protection Agency. 2023. "Battery Energy Storage Systems (BESS): Main Considerations for Safe Management." <https://www.epa.gov/electronics-batteries-management/battery-energy-storage-systems-main-considerations-safe>.

¹⁵ 1st Source Metal Halide (1SMH). n.d. "BYD Battery vs. Lithium-Ion Battery: Key Differences." 1SMH. Accessed January 22, 2026. https://www.1smh.com/byd_vs_lithium_ion.html.

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¹⁷ Unpopular Truth. 2025. "The Pros and Cons of Utility-Scale Battery Storage." Unpopular Truth, July 25, 2025. <https://unpopular-truth.com/2025/07/25/pro-and-cons-of-utility-scale-battery-storage/>.

¹⁸ Trahey, Lynn, Fikile R. Brushett, and Nitash P. Balsara et al. 2020. "Energy Storage Emerging: A Perspective from the Joint Center for Energy Storage Research." *Proceedings of the National Academy of Sciences* 117 (23): 12550-12557. <https://doi.org/10.1073/pnas.1821672117>.

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BATTERY SAFETY

This factsheet presents an overview of battery safety considerations for energy storage systems, or large stationary batteries installed in residential, commercial, and industrial settings.

KEY TAKEAWAYS



Battery Management System

Battery Management System (BMS) is a required component in all multi-celled batteries that controls and monitors the operation of the battery to ensure its safe operation. The BMS is designed to shut off the battery if it detects early signs of battery failure to prevent safety incidents.



Battery Fire Awareness

Battery fires can occur due to internal malfunction or proximity to extreme heat or external fire. Thermal runaway occurs when a battery heats up faster than the heat can be dissipated, resulting in the venting of hazardous gases and the potential for ignition or explosion.



Safety Standards

Robust and continuously updated safety codes and standards exist to ensure the highest quality of battery manufacturing and the safe operations of battery systems for every application.



Safety Tips

Organizations like the Fire Safety Research Institute publish easy-to-follow battery safety tips for everyday battery use, like those on their Take Charge of Battery Safety website, here: <https://batteryfiresafety.org/#section-1>

BATTERY MANAGEMENT SYSTEMS

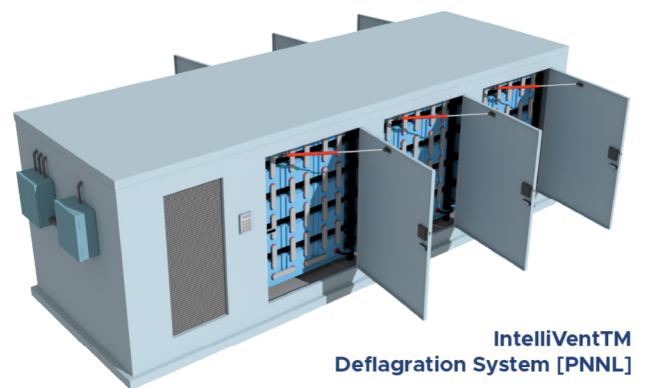
Batteries are regularly used in many of the devices and systems in our homes and daily routines. To ensure those systems remain safe and secure, high safety standards for battery manufacturing and operation are necessary. Large scale stationary batteries, like those used in residential, commercial, and industrial battery energy storage systems are similar to the lithium-ion batteries used in many other consumer products, but batteries used for energy storage systems have much higher capacities and energy densities. This is achieved by stacking multiple smaller battery cells within a single enclosure or battery unit.

Since these larger batteries contain multiple battery cells operating together at higher energies, they are required to be controlled by a **Battery Management System**, or BMS. Any battery system that contains multiple battery cells must have a BMS, including small power tools, e-bike packs, electric vehicles, and battery backups. The BMS controls and monitors the operation of the battery, including its current, voltage, state of charge (SOC), and its operational status (charging, discharging, or idle). The role of the BMS is to ensure that the battery operates safely and according to specifications, as well as to detect potential battery failures and power off the device to prevent safety incidents. The batteries in electric vehicles are required to have sophisticated **BMS to control and protect the energy storage system**, as well as to alert the driver of any potential failures or safety risks. While the BMS serves as a critical safety and control system, it **does not protect the battery from misuse or physical impact**, which is the main cause of battery failures in smaller transportation devices like e-bikes and scooters.

BATTERY FIRE AWARENESS

Even with a BMS and proper use, safety incidents and battery failures can still occur. Battery fires can start from a cell or other internal electrical failures, or if the battery is exposed to extreme heat or fire. It is important to note that a BMS cannot dissipate the heat of an active fire that reaches the battery. **If a fire reaches a battery, immediately evacuate the building, call the emergency fire dispatch, and inform them of the presence of a battery system.** A battery fire will also release toxic gases similar to those emitted by a house fire that are dangerous and should not be inhaled. In the case of a battery fire, evacuate to a ventilated area upwind of the fire.

If the battery itself fails and begins to overheat, this can cause a chain reaction called thermal runaway, where the battery begins to heat up so rapidly that it catches fire. If this happens, the safety protocol is the same—evacuate, call emergency response, and notify emergency services of the battery fire. The National Fire Protection Association (NFPA) mandates that the BMS of all batteries are designed to detect overheating before it leads to thermal runaway and have the capabilities to vent the system, as well as implement fire suppression measures and planning. Systems designed to reduce the potential for explosions do so by exhausting flammable gases, known as deflagration prevention, or by directing pressure waves through passive vent openings¹.



IntelliVent™
Deflagration System [PNNL]

Figure 1. Intellivent™ Deflagration System: A safety venting system for energy storage system enclosures.

SAFETY CODES AND STANDARDS

Standards and safety organizations like UL Solutions exist to ensure batteries are rigorously tested and manufactured to the highest safety standards. The most common battery failures occur with batteries that are purchased from countries that do not adhere to the latest UL safety standards. Before purchasing a battery or a product that contains a battery, be sure to check that it is UL Listed or Certified. Look to see that the product has a UL label like the one pictured here. A product with this label is required to meet specific safety standards and undergo rigorous safety testing.



There are numerous safety codes and standards that battery manufacturers are required to follow when producing batteries for sale in the United States. Stationary batteries, like those in residential,

commercial, and industrial sectors, must adhere to siting and permitting requirements that vary based on local regulations and type of system. For example, commercial and industrial batteries are subject to strict requirements to ensure that these larger systems have proper ventilation, access, and protection from the weather and other hazards². The following resources provide additional details on standards and safety:

UL Solutions

<https://www.ul.com/resources/battery-standards-overview>

National Fire Protection Association

<https://www.nfpa.org/education-and-research/home-fire-safety/lithium-ion-batteries>

National Electric Safety Code

<https://standards.ieee.org/products-programs/nesc/>

International Fire Code

<https://codes.iccsafe.org/content/IFC2024V1.0/chapter-12-energy-systems>

The key codes and standards for stationary energy storage systems are depicted in figure 2. These standards cover everything from fire and smoke detection, fire suppression and smoke containment, ventilation and thermal management, egress and access, electrical safety and emergency shutoffs, protection from hazards, necessary signage, spill containment and disposal, and communications and management. Project planners can engage with local first responders and permitting authorities during the project development process to help increase situational awareness, share lessons learned, and foster a collaborative approach to safety.

When a battery system is commissioned for use, critical safety and verification procedures are performed to ensure safe operation of the battery. All components, controls, and safety systems will be verified for correct installation and operation, the system will be inspected for any defects, and the commissioner will ensure that the owner has been provided with the complete documentation to ensure smooth ongoing operations, including maintenance and troubleshooting procedures.

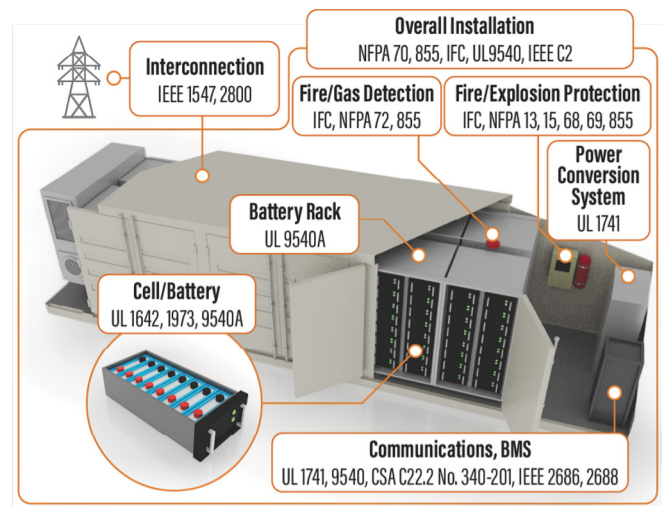


Figure 2. Key codes and standards for battery energy storage systems (BESS).

BATTERY SAFETY TIPS

While this factsheet is primarily focused on larger stationary batteries, the most common devices to suffer battery failures that lead to fires and safety incidents are smaller consumer products such as battery-powered scooters, bikes, and skateboards, followed by laptops, cellphones, tablets, and power tools. Each of these devices is relatively light-weight and mobile. With this mobility and ease of use comes the risk of physical damage to the battery. Below are some important safety tips to reduce the risk of battery failures:

- If the battery is damaged, do not use or charge it.
- Never charge a battery with the wrong cable. Avoid extension cords, and never daisy-chain or link multiple extension cables. Charging or discharging a battery with a cable other than what it is rated to use can lead to overcharging, overheating, and rapid failure.
- Place batteries on a flat, well-ventilated surface while charging to avoid overheating.
- Store batteries in a cool, dry place. It may not be best to store batteries in a garage, as garages can get significantly warmer or cooler than the rest of your home during the summer or winter.
- Do not store the battery fully charged or completely empty. It's best to store batteries between 30–80 percent charged.
- Do not store batteries plugged into their charger.

FURTHER READING

For additional safety tips, and to learn more about battery safety, check out:



Paiss M.D., V.L. Sprenkle, L. Khair, and M. Leitman. 2024. *Battery Energy Storage System Safety Report; Design Considerations for Electric Cooperatives*. PNNL-36330. Richland, WA: Pacific Northwest National Laboratory.
https://www.pnnl.gov/main/publications/external/technical_reports/PNNL-36330.pdf.



Twitchell, Jeremy B., Powell, Devyn W., and Paiss, Matthew D. 2023. *Energy Storage in Local Zoning Ordinances*. PNNL-34462. Richland, WA: Pacific Northwest National Laboratory.
<https://doi.org/10.2172/2204502>.



Fire Safety Research Institute, UL Research Institutes. 2025. *Take Charge of Battery Safety*.
<https://batteryfiresafety.org/#section-1>.

¹ While the international fire code (IFC) that references these NFPA deflagration (NFPA 69 and NFPA 68) and fire suppression (NFPA 855) standards are updated regularly, these updates are inconsistently adopted across the United States. For example, Puerto Rico adopts the International Codes (I-Codes), which are on the 2018 edition of the IFC.

² For more information on how safety influences planning and zoning considerations, see: Twitchell, Jeremy B., et al. "Energy Storage in Local Zoning Ordinances," Oct. 2023. <https://doi.org/10.2172/2204502>.

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LOCAL SITING AND PERMITTING FOR ENERGY STORAGE

This factsheet describes the landscape of local zoning, siting, and permitting regulations and processes for battery energy storage systems (BESS) projects. **Zoning** refers to general local land use regulations; **siting** refers to the process of approving where a project may be built; and **permitting** refers to the overall process of receiving all necessary approvals from government bodies.

These processes are critical steps for all energy projects, including energy storage. Adopting a local zoning ordinance that clarifies siting and permitting regulations for BESS can reduce uncertainty and enable more efficient project review.

NAVIGATING THE LOCAL REGULATORY LANDSCAPE FOR ENERGY STORAGE

Most BESS projects will require zoning approval from an “authority having jurisdiction” (AHJ) to move forward with construction and commercial operation. In most cases, this refers to local (town, city, or county) governments, although some energy projects in some states may only require state land use approval. Local approvals for siting and permitting are one of the leading causes of delays or cancellations of energy projects, including energy storage¹.

In many cases, local planning officials who have authority over project approvals may lack familiarity with BESS technologies, which are still relatively new.

Additionally, unlike many other energy infrastructure projects, BESS are modular and can be built near other land uses, including homes and businesses. This makes siting BESS somewhat unique².

Planners may face uncertainty about reasonable zoning decisions that balance safety, local impacts, and other goals. Uncertainty about siting and permitting at the local level has led some developers to withdraw projects, and has spurred moratoria or bans on energy storage projects in some areas.

WHY ARE ZONING ORDINANCES IMPORTANT?

Local zoning ordinances enable efficient and balanced siting and deployment of BESS projects. Without a zoning ordinance in place that establishes where projects may be sited and standard requirements they must follow, each proposal generally requires a time-intensive conditional use permit.

Zoning ordinances for BESS can reflect local needs and preferences and offer an opportunity to incorporate existing best practices into local regulations, all of which can help ensure that projects are deployed in ways that align with a community's values, maximize local benefits, and minimize risks.

ELEMENTS OF AN ENERGY STORAGE ZONING ORDINANCE

In order to offer clear guidelines for project developers, maximize benefits, and ensure local safety, zoning ordinances for BESS generally contain certain common elements³.

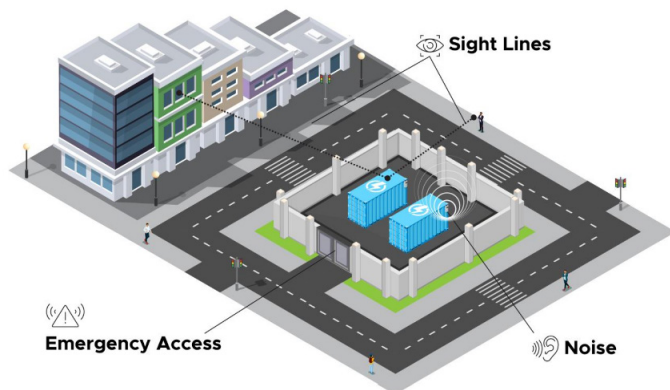


Figure 1. Illustrating potential local energy storage impacts and considerations for siting a utility-scale energy storage system, including visual impacts, noise, and first responder access.

DEFINITIONS AND GENERAL REQUIREMENTS

Some of the most fundamental building blocks of a local BESS zoning ordinance include information about the size and type of systems being regulated and where they may be built.

Definitions of key terms, including, for example, “battery energy storage system,” can reduce confusion and streamline approvals. Uniform definitions are commonly adopted from language in codes and standards, such as National Fire Protection Association (NFPA) 855.

Size tiers or cutoffs are important to clarify what system size regulations apply to. For example, systems over 600 kWh in capacity, or “Tier 2” systems, may be permitted in fewer zones than smaller or “Tier 1” systems, or may require greater property line setbacks (600 kWh is a common cutoff size presence in many regulations. Codes and standards, including the International Fire Code (IFC) and NFPA 855, establish additional safety and enclosure requirements above that size)⁴. These cutoffs typically intend to distinguish larger, utility-scale systems from smaller community-scale or residential-scale projects.

Permitted zones described in an ordinance clearly specify which areas certain BESS projects may be constructed by right. Ordinances may also specify whether systems are allowed in additional zones with a conditional use permit. Larger or “Tier 2” systems are generally more restricted, often to industrial, manufacturing, and potentially certain commercial zones. Smaller systems may be permitted by right in more zones, including commercial and residential zones. Specific permitted zones may vary from place to place based on each area's land use patterns, density, and local preferences.

VISUAL, LIGHTING, AND NOISE REQUIREMENTS

Other elements of local zoning ordinances include steps to ensure projects minimize disturbance to neighboring homes and businesses and fit in with other uses and the overall character of an area.

Setbacks from property lines, buildings, and roads help establish clear siting rules for BESS projects that maintain safety, privacy, and neighborhood character. Setbacks may vary by zone. A setback of 100 feet is a common requirement, and is based on standard specified in the NFPA 855.

Fencing or visual screening requirements are common, and establish rules about whether commercial BESS installations must be enclosed by fencing or vegetation. These rules may specify the height, materials, and overall appearance of screening fences or barriers, and are often designed to ensure installations are hidden from the view of neighbors and passersby. See Figure 2 for an example.

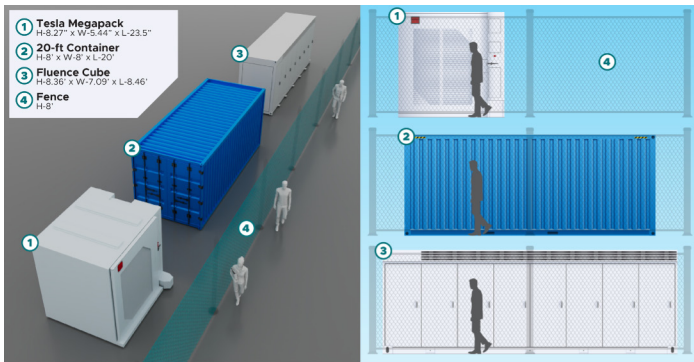


Figure 2. Visual screening requirements are common in local zoning ordinances for battery energy storage systems (BESS). Illustrated here is an example of a standard 8-foot screening fence against common commercial BESS installations.

Lighting and noise requirements generally exist to protect neighboring properties from unnecessary disturbance. Common requirements include that lighting be downcast or minimized, or that noise heard from neighboring properties or the street be kept below a maximum decibel level.

SAFETY AND PLANNING REQUIREMENTS

Ensuring that a proposed BESS adheres to safety best practices is a critical consideration for local permitting. Relevant codes and standards, including NFPA 855 and recent editions of the IFC, include safety and decommissioning steps. Some areas adopt and refer to these codes or standards, while others may adapt more individualized language directly into their zoning ordinance.

Decommissioning plans and funds establish requirements for the end of a system's life. In decommissioning plan, BESS operators must describe all steps, roles, and responsibilities needed to remove all components of a system and mitigate any waste. Some regulations may also require decommissioning funds, which can take the form of a bond or letter of credit, to pay for decommissioning. Decommissioning plans, but not funds, are described in NFPA 855.

Site plan requirements describe what details must be submitted to local officials for a system to receive a permit. This can include technical specifications, contact information for project owners and installers, and emergency plans. NFPA 855 also describes site plan elements, including diagrams, plans, and specifications that should be submitted for approval.

Additional safety requirements address basic safety concerns with language focused on protecting community safety and enabling quick first responder access in the case of a fire. These requirements can include hazard mitigation steps, like clearing vegetation near a battery to reduce fire risk. These can also include emergency access requirements in case of an incident, including ensuring that the facility has available water and ensures access for emergency services.

RESOURCES

If your town, city, or county is considering adopting or updating a zoning ordinance to include energy storage, it can be helpful to refer to relevant codes and standards as well as to model ordinances developed by states or the research community.

CODES AND STANDARDS

NFPA 855: NFPA 855 is the Standard for the Installation of Energy Storage Systems. First released in 2020, the standard's 3rd edition was published in 2026. NFPA 855 reflects current science and best practices intended to ensure that BESS of all types, including but not limited to common lithium-ion batteries, are designed and operated safely. While NFPA 855 contains extensive technical details, many of its components are relevant to siting and zoning, including emergency response plans, site plan and decommissioning requirements, and fire and explosion control systems.

IFC (2021 and onward): The IFC covered specifications for "Electrical Energy Storage Systems" in Chapter 12, Section 1207 of its 2021 edition. This section requires fire testing and other protection measures in order for a BESS to comply with fire regulations. Any AHJ that has adopted the 2021 or more recent version of the IFC into its fire or building codes will have these requirements in place for any proposed BESS projects.

MODEL ORDINANCES

Some states and other entities have created model ordinances that can be adapted by local governments. These include New York’s Battery Energy Storage System Guidebook⁵, California’s draft BESS Model Ordinance and Guidance⁶, and the University of Michigan’s Planning and Zoning for Battery Energy Storage Systems guide⁷. While each of these models is geared toward local governments in that state, these models may be useful as references to local planners nationwide.

¹ National Caucus of Environmental Legislators. n.d. “Clean Energy Siting and Permitting Fact Sheet,” accessed January 23, 2026, <https://ncelenviro.org/resources/clean-energy-siting-and-permitting-fact-sheet/>.

² Jeremy B. Twitchell et al., *Energy Storage in Local Zoning Ordinances*. 2023. PNNL-34462, Pacific Northwest National Laboratory (PNNL), Richland, WA. <https://doi.org/10.2172/2204502>.

³ Devyn W. Powell and Jeremy B. Twitchell. 2026. *Principles and Options for Designing Battery Energy Storage Zoning Ordinances*, PNNL-37956, Pacific Northwest National Laboratory (PNNL), Richland, WA. <https://doi.org/10.2172/3013849>.

⁴ For example, the 2021 International Fire Code states that the capacity of a lithium-ion or flow BESS in a single room or unit should not exceed 600 kWh unless fire testing and a hazard mitigation analysis have been completed. NFPA 855 requires a hazard mitigation analysis for systems above that size. *NFPA 855: Standard for the Installation of Stationary Energy Storage Systems*, 3rd ed., 2026, <https://link.nfpa.org/all-publications/855/2026>; *International Fire Code, Chapter 12: Energy Systems*, August 2025, https://codes.iccsafe.org/content/IFC2021V2.0/chapter-12-energy-systems#IFC2021V2.0_Pt03_Ch12_Sec1207.1.

⁵ New York State Energy Research and Development Authority (NYSERDA). 2021. “New York State Battery Energy Storage System Guidebook,” <https://www.nyserda.ny.gov/All-Programs/Clean-Energy-Siting-Resources/Battery-Energy-Storage-Guidebook>.

⁶ California Governor’s Office of Business and Economic Development. October 2025. “GO-Biz Renewable Energy Permitting Initiative,” <https://business.ca.gov/industries/climate-and-clean-energy/go-biz-renewable-energy-permitting-initiative/>.

⁷ University of Michigan Graham Sustainability Institute. 2024. *Planning and Zoning for Battery Energy Storage Systems: A Guide for Michigan Local Governments*. <https://graham.umich.edu/media/files/BESS-guide.pdf>.

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EFFECTIVE PARTICIPATION IN ENERGY STORAGE SITING PROCEEDINGS

This factsheet contains guidance for participating in energy storage siting proceedings through expert testimony and public comments. **Public comments** provide formal opportunities to share local knowledge, experiences, and concerns that may affect siting decisions. **Expert testimony** translates technical information into clear, evidence-based insights for decision-makers.

KEY TAKEAWAYS

	Public Comments	Expert Testimony
What is it?	Written or oral statements submitted during formal comment periods that become part of the official decision record	Technical evidence presented by a qualified expert within a formal, contested case process and subject to specific procedural and evidentiary rules
Who can provide it?	All interested parties (submission may require registration as a formal docket participant)	Qualified expert witnesses invited or retained by a party to the docket to address specific technical issues
Where is it accepted?	Public comment periods or hearings where agencies review draft documents and proposals to identify issues, concerns, and potential impacts	Contested case hearings or proceedings where technical evidence is introduced and evaluated, particularly when issues are disputed or complex
How to make it effective?	• Provide specific, focused input as early as allowed • Use relevant facts, data, and examples • Add value to the record by offering clear, timely, and original perspectives	• Explain methods, data, and assumptions • Ground opinions in standards and evidence • Follow professional ethical obligations

PUBLIC COMMENTS

WHAT

Public comments are written or oral statements submitted by individuals, organizations, or stakeholders. The comments are received during a formal comment period to provide input on a proposed project, permit, or environmental review (e.g., energy storage siting and permitting through an environmental assessment or environmental impact statement)¹.

WHY

Public comments are a required part of many regulatory and environmental review processes and ensure that agencies consider perspectives from all interested parties. This includes local knowledge, community concerns, and advocacy interests, technical information, and potential impacts before making siting or permitting decisions.

HOW

To make effective public comments, it's important to first decide if commenting is the best avenue for your goal. Commenting is one way to engage, but sometimes other input mechanisms, such as meetings or direct engagement, are also effective². Comments that are common positions or broad concerns are less likely to be considered significant. Including relevant facts, data, and analysis can make public comments impactful³. Examples include site-specific observations, comparisons to similar projects, or local environmental and community statistics. References to applicable sections of regulatory documents can also make comments more impactful while anchoring points precisely to the topic under review.²

GOOD PRACTICES

Identify the comment

opportunity: Confirm the project, agency, docket number, and comment deadline. Determine whether comments are being accepted on a permit application, siting decision, or environmental review document.

Review the relevant

materials: Read the proposal or environmental document. Focus on areas needing clarification, correction, or additional analysis.

Define your perspective and

purpose: Clarify who you are and what you want the agency to consider, change, or further evaluate.

Identify all your specific

issues or impacts: Some processes will not allow issues to be raised later if not identified early on.

Support your points with

context: Use personal experience, local knowledge, data, or references to standards and studies where appropriate. Clearly explain how the context relates to the proposed project.

Add value to the record:

It is fine to concur with previous comments but consider focusing on new insights or context rather than repeating points already raised.

Use clear, respectful language:

Write in plain language and define technical terms when needed. Maintain a professional, respectful tone to ensure comments are taken seriously.

Reference specific sections

when possible: Cite page numbers, sections, or figures from the proposal or environmental document to help reviewers understand your comments.

Submit comments on time and through the correct

channel: Adhere to the stated deadline using the required method (i.e., online portal, email, or public hearing) so your comment will be considered.

STRUCTURE YOUR COMMENT CLEARLY:

1

Introduce yourself and your interests

2

Summarize key points up front

3

State the issue or concern

4

Explain why it matters

5

Describe what action or consideration you are requesting

EXPERT TESTIMONY

WHAT

Expert testimony is a formal process in which qualified individuals are invited or designated to provide technical analysis under specific procedural and evidentiary rules. Those invited to provide expert testimony are considered **expert witnesses** who offer opinions based on their education, training, skill, or experience⁴. A presiding authority determines whether an individual qualifies as an expert based on expertise relevance, credentials, and experience with the issue at hand⁵.

WHY

In energy storage siting proceedings, expert testimony helps decision-makers understand complex energy storage issues that fall outside the general knowledge of a judge, hearing officer, board, or zoning commission. Topics addressed may include:

- areas of uncertainty or conflicting viewpoints
- technical aspects of a proposed energy storage project
- compliance with engineering standards and safety protocols

- cost, benefit, and economic considerations
- grid impacts, system performance, and reliability implications
- technical factors relevant to siting and permitting decisions

HOW

An expert testimony is typically developed by individuals invited or retained by a party to the docket to address specific technical issues⁴. Effective testimonies demonstrate integrity, clarity, objectivity, and professionalism so that opinions are perceived as credible technical analysis rather than advocacy.⁶ Experts should also be transparent about their methodology by grounding opinions in relevant data or standards and clearly explaining data sources and assumptions. Experts should also remain within the scope of their professional expertise and adhere to applicable professional codes of ethics. When ethical obligations and legal strategies appear to conflict, the expert's professional ethical standards should guide their conduct and testimony⁷.

GOOD PRACTICES



Confirm your qualification and role: Ensure your education, training, and professional experience directly relate to the proceeding.



Define the technical question you are addressing: Identify the specific issue, assumption, or uncertainty in the record that your testimony is intended to clarify.



Develop opinions grounded in reliable evidence: Use appropriate data, accepted practices, and applicable standards or guidelines, and avoid speculation or unsupported assumptions.



Explain your methodology clearly: Use transparent reasoning so others can track your conclusions.



Communicate in clear, accessible language: Use plain language where possible and define technical terms.



Follow professional and ethical standards: When ethical obligations and legal strategy appear to conflict, allow professional ethics to guide your testimony.



Review your testimony: Check for consistency, clarity, and alignment with the proceeding's scope.

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LOCAL COMMUNITY ENGAGEMENT FOR ENERGY STORAGE DEVELOPERS

This factsheet presents an overview of the value of an effective local engagement strategy and summarizes best practices and key considerations for local engagement for energy storage project developers.

KEY TAKEAWAYS

 Regulatory Compliance	Depending on the jurisdiction, energy storage projects may be required by law to include some level of public participation or stakeholder engagement in the planning process.
 Reducing Local Opposition	Early and meaningful engagement with the community helps reduce opposition and builds trust between project planners and local populations. Trust fosters collaborative relationships, minimizes local resistance to projects, and addresses concerns before they escalate.
 Improved Project Outcomes	Gathering local input can ensure that energy storage projects better align with community needs and preferences, which can lead to more optimal planning and siting outcomes for both the project and local residents.
 Challenges and Barriers	Community members may find some public engagement efforts inaccessible due to technical jargon, lack of clear processes and opportunities for participation, and time constraints, but these barriers can be addressed.
 Principles of Community Engagement	Local perspectives are not often effectively incorporated into energy project design and siting decisions. Following established principles of community engagement can improve processes and outcomes for project developers and for all stakeholders.

CONFIRM REQUIREMENTS FOR PUBLIC ENGAGEMENT

Federal, state and local requirements for local engagement with energy projects vary by project location, type, and size. Many state and local laws require a certain level of stakeholder or public engagement as part of the permitting process.

If you are planning a project, check with your local [state energy office](#) and other authorities having jurisdiction (AHJs), which can include city, town, or county governments, for specific requirements and guidance around public engagement for energy storage projects.

EFFECTIVE ENGAGEMENT CAN REDUCE OPPOSITION AND BUILD TRUST

Local opposition is frequently cited as a source of delay for energy storage projects.¹ This opposition can impact permitting timelines or lead to legal challenges. In some cases, community concerns about project location, technology safety, or other local impacts have led some towns, cities, or counties to adopt moratoria against energy storage projects entirely.² More opposition and distrust is likely when the local perception is that public engagement efforts have occurred too late in the planning process, seem perfunctory, or are not effectively tailored to their local context.^{3,4}

Project developers who prioritize transparent decision-making with frequent and proactive opportunities for community input can reduce opposition, improve overall public support, enhance trust, and reduce local concerns about a project's potential risks, which are increasingly prevalent in reaction to proposed energy storage projects.^{5,6} A single consultation or meeting may be insufficient to address significant or evolving local concerns. Early and ongoing engagement ensures that people who live or work near a proposed energy storage or other energy project feel their concerns are acknowledged and addressed.⁷

Community engagement can also enrich energy project planning and lead to better outcomes. For example, local feedback can help developers ensure that projects are planned and sited in ways that align with local needs and preferences. This can include minimizing disruptions to viewsheds, agriculture, and other land uses.⁸

CHALLENGES AND BARRIERS

Effectively enabling local input and incorporating community perspectives into a project can be challenging for both local residents and project developers.

First, energy projects can be complex. Energy storage technologies, in particular, are relatively new and may be unfamiliar to many members of the public. This lack of technical familiarity may pose a barrier to informed participation.

Additionally, some opportunities to offer input may not be accessible to all. For example, in-person public meetings may limit participation from people with work conflicts or other constraints.⁹

Project developers may also need to work to overcome preexisting local concerns as part of their engagement efforts, especially if residents of an area already hold negative perceptions about energy storage or have had challenging experiences with other projects or developers.⁵

Integrating additional public input steps into a planning process can also create additional workload and time demands for project developers, who may have limited resources. However, an upfront investment in local engagement can mean less effort and time spent responding to opposition later in the process.

STRATEGIES FOR EFFECTIVE LOCAL ENGAGEMENT

Following established principles for thoughtful, effective public engagement can help lead to positive outcomes. These principles include:

- **Recognition:** acknowledging and addressing local perspectives and experiences. This includes considering how a specific community may have been impacted by past decisions about energy or other infrastructure projects.
- **Procedural:** focusing on enabling fair, transparent and accessible participation. This can include planning public meetings at specific times or locations to enable more participation, or offering multiple avenues for providing input.
- **Distributive:** ensuring that developers consider the distribution of both positive and negative impacts of an energy project. For energy storage projects, this may mean addressing concerns that one town or neighborhood will have to bear the impacts of a project whose benefits may flow to other utility customers, for example.²

There are also many effective strategies developers can use to develop resources and approaches that enable informed local participation and build trust. These can include:

- **Outreach to Trusted Messengers:** Collaborating with influential voices, including local governments, community leaders, and key organizations can help developers build effective relationships and offer valuable insight into effective approaches for a particular local context.
- **Plain-Language Materials:** Developing resources that explain technical concepts, planning objectives, and methodologies in plain language with minimal jargon.
- **On-Demand Resources:** Offering frequently asked questions and key details on project websites can ensure community members can access important information on their own time.
- **Interactive Training Sessions:** Hosting effectively facilitated in person or virtual workshops that offer members of the public opportunities to ask questions can enable constructive dialogue.
- **Regular Updates:** Developers can ensure communities are kept informed throughout the planning cycle and see how their input is being incorporated by providing regular updates on progress, findings, and upcoming decision points through multiple avenues, including communication at meetings or workshops and regular website updates.¹⁰

MECHANISMS FOR IMPACTFUL FEEDBACK

Accountability is incomplete without mechanisms for tracking and evaluating engagement efforts. Using metrics to assess outreach efforts can provide developers with data to improve future processes and can help demonstrate to the public that their participation is valued and impactful.¹¹ Possible tools and metrics for documenting and evaluating the success of public engagement may include:

- **Engagement Depth:** While developers commonly track and report on the number of outreach events conducted, it can also be helpful to track levels of participation. Total attendance, representation from key sectors, number of meetings attended, or information about the type and complexity of feedback provided can offer a fuller picture of outreach efforts.

- **Community Perception:** Collecting feedback from participants through surveys or interviews can illustrate how engagement efforts have impacted local perceptions of a proposed project and developers' transparency and responsiveness to local needs.
- **Decision-Making Impact:** Documenting how community input influenced project decisions can demonstrate transparency and accountability.

SUMMARY

Local community engagement in energy project planning generates outcomes that benefit both planners and communities, providing mutual value through collaboration and shared responsibility. Effective local engagement is especially important for energy storage projects, which have increasingly faced challenges due to local concerns and opposition.

By incorporating public perspectives into the planning process, energy storage project developers can take steps to overcome these concerns and can also gain insights that lead to more effective and efficient project implementation.

Members of the public, meanwhile, can benefit from opportunities to meaningfully participate in the decision-making processes that impact their energy system, strengthening resilience and ensuring that projects enhance local benefits.

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⁹Promising Practices for Meaningful Public Involvement in Transportation Decision-Making. 2022. United States Department of Transportation. <https://www.transportation.gov/sites/dot.gov/files/2022-10/Promising%20Practices%20for%20Meaningful%20Public%20Involvement%20in%20Transportation%20Decision-making.pdf>.

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¹¹Ibrahim Adeiza Ahmed et al., "Measuring the Invisible: A Framework for Quantifying Energy Justice in Urban Communities in the United States," Energy Research & Social Science 122 (April 2025): 103986, <https://doi.org/10.1016/j.erss.2025.103986>.

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MICROGRIDS

This factsheet presents an overview of the benefits and use cases of microgrid systems, implementation challenges and potential solutions, planning considerations, and project timelines for their development.

KEY BENEFITS

 Access	Microgrids provide access to locally generated energy for remote communities who may not be grid-connected. Microgrids can also provide energy for communities whose utility generation mix comes at a high cost or adversely impacts local air quality.
 Affordability	Microgrids can reduce the cost of electricity by using local generators, providing an alternative to utility-purchased electricity and avoiding transmission and distribution costs. Local generators that do not rely on purchased fuel can also provide additional cost savings, especially in remote locations with limited accessibility. These savings can reduce local energy burden and prevent shutoff notices for utility non-payment.
 Improved Air Quality	Microgrids that do not rely on purchased fuel can replace the need for backup diesel powered generators or utility-purchased electricity, providing local air quality improvements and health benefits.
 Resilience	Microgrids provide resilience to grid outages, whether the result of local grid conditions, extreme weather events, or public safety power shutoffs. By automatically disconnecting from the main grid during these events, a microgrid can provide uninterrupted access to electricity—this is especially important for critical infrastructure, such as hospitals and community gathering spaces.
 Social Impact	Microgrids provide an alternative to traditional, utility-purchased electricity. This can allow microgrids to serve as a community asset, not only providing energy independence, but allowing for wealth creation, community ownership, and community building.

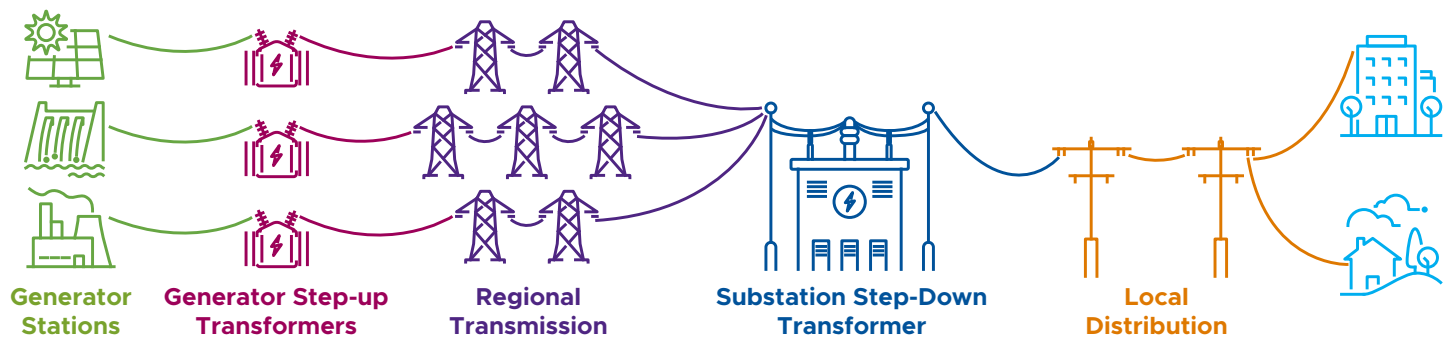


Figure 1. Representation of the electric grid from generation stations (left) through the transmission system to the substation (middle) and then distributed to the local loads (right).

THE ELECTRIC GRID

The traditional **electric grid** was designed to transmit the electricity generated by large resources across long distances to towns and cities and then distribute that electricity to communities, houses, businesses, and other buildings to meet their needs. The electricity generated by these larger generators at the edge of the grid is first stepped up to a higher voltage using transformers so that it can be transmitted great distances without losses. Once the electricity reaches the local distribution substation, it is stepped down to a lower, safer voltage to then be distributed to the end users of electricity. This pathway is described in Figure 1.

OVERVIEW

In this traditional scenario, homes, communities, and businesses consume power that was generated miles away, relying on the safe and uninterrupted operation of every component of the grid connecting them. In contrast, a **microgrid** is a **local electric system connecting smaller, on-site generation sources directly with electricity consumers**. A microgrid can be connected to the main grid to import or export electricity, or it can operate in **islanded mode** by **disconnecting from the grid and operating as an independent system**. Microgrids can switch between these modes using a controller to open or close the switch between the main grid and the microgrid.

When the microgrid is disconnected from the main grid, the local generators and consumers operate as an island, with the controller balancing the demand of the loads (consumers) with electricity from the generators (rooftop, on-site, or nearby) and the energy storage (batteries), as seen in Figure 2. Operating in **islanded mode provides those connected via a microgrid with electricity access even during a power outage on the main grid**. Outages can occur due to unreliable grid conditions, maintenance, extreme weather, or public safety power shutoff events.

MICROGRID USE CASES

Microgrids can be relatively small, containing just one house, rooftop generation, and a battery. Microgrids can also be scaled up to power a community of multiple homes and community centers using a combination of generation sources and energy storage devices, all connected with the required electrical components, such as power converters to convert direct current (DC) to alternating current (AC) and protection relays to sense disturbances in the main grid to signal the controller to disconnect or reconnect the microgrid. The possible components of a microgrid are pictured in Figure 2.

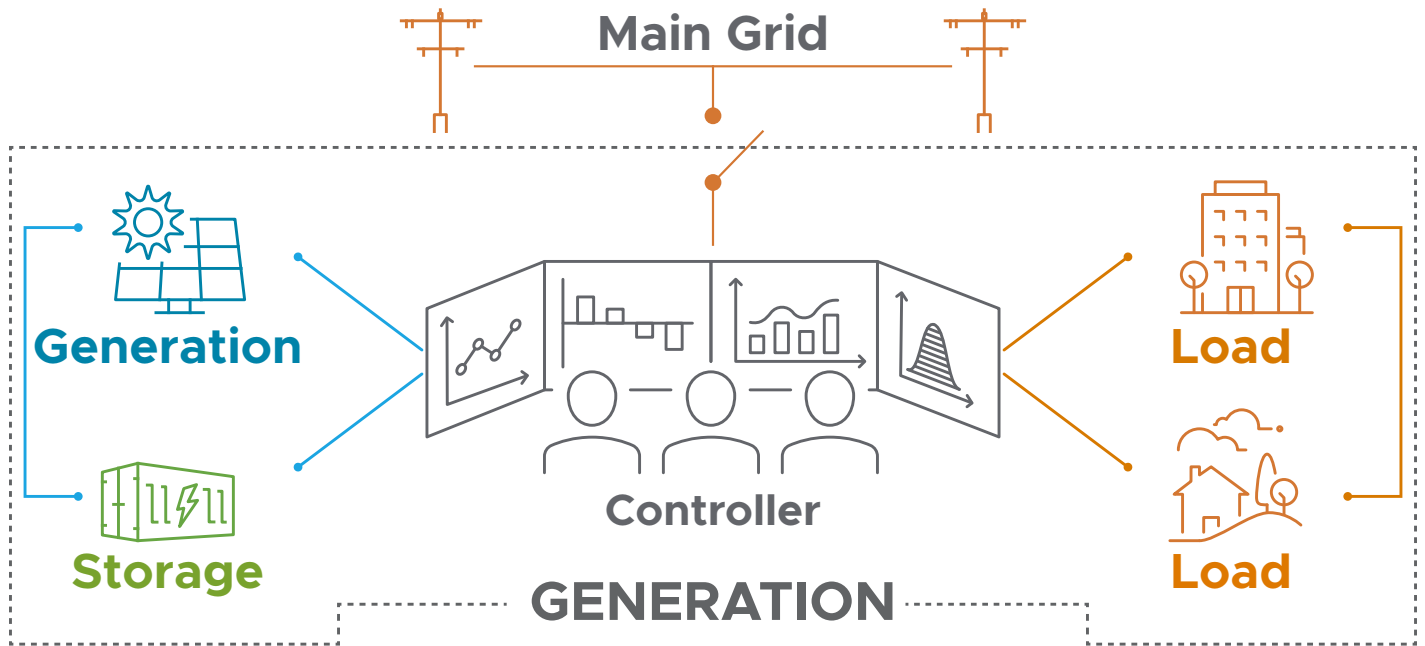


Figure 2. Microgrid components (dashed box) and switch connection to the main grid (top).

BEFORE PURSUING A MICROGRID

While a microgrid can provide numerous community benefits, it is important to consider simpler, less expensive energy measures as precursors to microgrid development. Improving energy efficiency can reduce electricity demand, lower energy costs, and potentially decrease the size and cost of a future microgrid system. Some example measures are described below.



Weatherization

Weatherization is the process of improving a building's physical condition to more efficiently use electricity. An energy auditor inspects the building to identify the most cost-effective measures to implement. The most common energy-saving measures are usually related to improving insulation and window and door sealing to reduce conditioned air loss. More information can be found at: <https://www.energy.gov/energysaver/weatherization>.

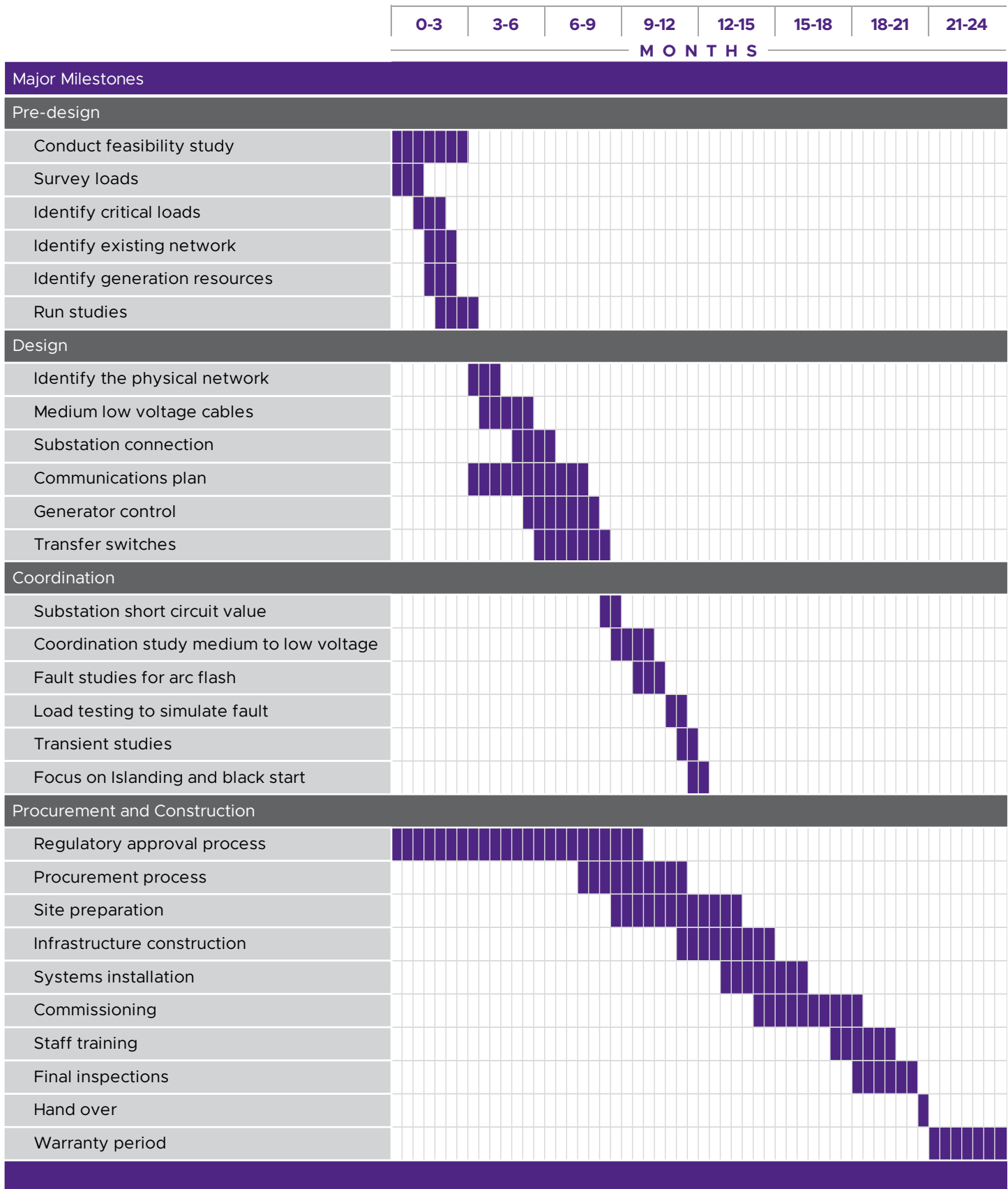


Energy Efficiency

Energy efficiency measures are any steps that can reduce the energy required to perform the same task; this can be as simple as replacing old, inefficient appliances with newer, high efficiency models. Energy efficiency can also be utilized as a design principle during a building's design and construction by using strategies such as maximizing solar heat gain and applying passive cooling techniques to make the most of solar heat gain and passive cooling techniques. More information can be found at: <https://betterbuildingsolutioncenter.energy.gov/efficiency/energy-efficiency/tech>.

MICROGRID CHALLENGES AND POTENTIAL SOLUTIONS

 Technology Risk	The technology used in microgrids is still evolving, which means that there is a risk of technical problems.	As of 2026, there were nearly 1,300 microgrid installations across the United States with a combined generation capacity of approximately 5,681 MW and 266 MW of energy storage. Standards organizations work to reduce this risk, as do regulators. Despite this growth, several technical, regulatory and financial challenges continue to affect microgrid deployment¹.
 High Cost	Microgrids can be expensive to install, especially if they are large or require substantial local generation.	It is important to weigh the upfront and operations and maintenance costs throughout the lifetime of the microgrid against the savings and benefits realized through reduced transmission, distribution, and utility costs, protection from market volatility, and improved resilience.
 Complexity	Microgrids are complex systems that require careful planning and design. They can be difficult to operate and maintain, especially in remote or harsh environments.	Process checklists aid design, implementation, and training. Lessons learned are also valuable planning and design resources. Third party service providers can also support this task.
 Vulnerability to Cyberattacks	Microgrids are connected to the internet, which makes them vulnerable to cyberattacks.	Sensors and protection equipment—such as Supervisory Control and Data Acquisition systems—control, collect, and store real-time microgrid operational data to maintain efficient and safe microgrid operation. Modern SCADA can be configured to shield or block cyber-attacks to prevent damage to infrastructure.
 Generator Intermittency	Local generators require either on-site fuel or generation resources, which may not always be available. This can lead to power outages if the demand for power exceeds the supply.	Long-term battery storage and backup generators can reduce these impacts, and microgrids can shed non-critical loads to lower demand during supply shortages.
 Limited Scalability	Microgrids are limited in their ability to scale up to meet the needs of large populations.	Microgrids are typically designed for localized areas such as campuses or communities and often operate in the 10–25 MW range. Scaling microgrids to serve larger populations introduces challenges related to system control, protection, communications, and cost. Addressing these challenges remains an active area of research.
 Lack of Standards	There are no universally accepted design or hardware standards for microgrids; this can make it difficult to design, install, and operate them.	However, organizations such as the Institute of Electrical and Electronics Engineers (IEEE) and the U.S. Department of Energy (DOE) have published guidelines and best practices to help address this gap to assist in developing resilient, efficient, and reliable microgrid systems.
 Resistance from Utilities	Utility companies may resist the development of microgrids, as they could see them as a threat to their business.	State regulators continue to challenge this paradigm. More states are beginning to adopt legislation facilitating microgrid development (CA, CT, ME, MA, HI, and Puerto Rico have such legislation)².
 Regulatory Hurdles	There can be regulatory hurdles to the development of microgrids, such as obtaining permits and licenses.	While regulators work to reduce these hurdles, some state energy offices provide guidance and resources to navigate the local regulatory landscape.
 Public Acceptance	There may be public opposition to the development of microgrids due to concerns about safety, environmental impact, and cost.	Microgrids support affordable, reliable, and resilient energy systems and provide energy security. Effective communication and educational resources can also be paramount to gaining public acceptance.



MICROGRID DESIGN PROCESS

The table below provides an example of the project development stages and timeline for a microgrid project. Note that actual timelines depend on a number of factors such as project size and complexity, supply chains, and interconnection procedures.

¹“Onsite Energy Installation Database.” 2026. U.S. Department of Energy. <https://www.onsite-energy-installations.ornl.gov/>

²Shea, Daniel. 2022. “Microgrids: State Policies to Bolster Energy Resilience.” National Conference of State Legislators. <https://www.ncsl.org/energy/microgrids-state-policies-to-bolster-energy-resilience> (March 20, 2026).

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END OF LIFE CONSIDERATIONS FOR BESS

This factsheet describes what occurs when a battery energy storage system (BESS) is retired from service, including decommissioning, recycling, and waste management considerations.

KEY TAKEAWAYS



DECOMMISSIONING

Multi-step process to take BESS out of service

Defined during permitting or early project development

Caused by capacity degradation, safety, obsolescence, or project needs



REPURPOSING/ SECOND-LIFE USE

Repurposing of stationary BESS is uncommon

Second life is primarily for electric vehicle battery packs converted to grid applications

Needs additional testing, reconfiguration, and certification



RECYCLING

Used to recover material and mitigate waste

Focus is on valuable metals in the cathode

Largest share of end-of-life costs



WASTE MANAGEMENT

Used for non-recoverable materials

Managed through approved disposal pathways

Must comply with federal and state hazardous waste regulations

DECOMMISSIONING

When BESS is no longer suitable for continued use, it is retired from service and decommissioned.¹ Decommissioning represents the final lifecycle stage for batteries that cannot be safely or economically repurposed. This state is typically triggered when battery energy capacity falls below operational thresholds for the intended service (typically 70–80 percent of original storage capacity).² Other factors such as obsolescence, site redevelopment, or contractual terms may also trigger retirement.

BESS decommissioning is a planned, multi-step process. Cost and implementation vary with geography, transportation distance, chemistry, and recycling technology.¹ In many cases, financial assurance (bonding, escrow, etc.) also may be needed to ensure decommissioning and site restoration can be completed.³

DECOMMISSIONING STAGES

There are 5 main stages of decommissioning:

- 1. **De-energize:** All electrical and mechanical energy sources are isolated. Lockout-tagout procedures are applied and batteries are prepared for safe handling.
- 2. **Disconnect:** Electrical and structural connections are physically disconnected, including battery containers, inverters, transformers, and switchgear.
- 3. **Material Sorting and Removal:** Decommissioned components get sorted and packaged for site removal. A logistics plan addresses transportation needs.
- 4. **Disposition:** Components are transported according to a defined disposition pathway (reuse/repurpose/recycle/dispose).
- 5. **Site Demolition and Restoration:** Remaining infrastructure is removed as required, and the site is restored to its original condition or prepared for an alternative use.

DECOMMISSIONING PLAN

A decommissioning plan is often required during the permitting process or early project development, though decommissioning may occur years later.⁴ The plan is used to document how decommissioning stages will be managed and executed.

Plan Element	Description
Safety	Addresses electrical hazards, fire risk, hazardous materials, training, personal protective equipment (PPE)
Logistics	Includes rigging plans, specialized lifting equipment, number and size of transports, site access constraints
Regulatory Compliance	Align with requirements from the local authority having jurisdiction, which can vary by state and site.
Disposition Strategy	Evaluate reuse, repurpose, recycle, resale, and disposal of all components. Battery chemistry and condition affect value and pathway choices.

REPURPOSING AND SECOND LIFE USE

The term **second life** is most commonly used to describe repurposing of electric vehicle batteries for stationary grid applications. In contrast, it is uncommon for stationary BESS already deployed for grid services to be repurposed.

Nevertheless, when battery systems are repurposed, they no longer meet original performance requirements but retain sufficient energy capacity for less demanding operating conditions.² This means the new application may have lower power requirements, reduced depth-of-discharge cycling, less frequent cycling, or more relaxed performance and response-time requirements compared to the system’s original design.

Repurposing typically requires additional testing, grading, and reconfiguration to verify safety and performance. This may include reconfiguring modules, updating battery management systems, and meeting certification, warranty, and liability requirements. These factors limit widespread second-life adoption for stationary BESS.

In limited cases, battery systems or components removed from service for non-performance-related reasons, such as site redevelopment, may be redeployed at another location for continued use as a BESS. Regardless of whether repurposing occurs, all battery systems ultimately require a defined recycling or disposal pathway.

RECYCLING^{5,6}

Even when batteries are repurposed or reused, they ultimately require recycling to recover materials and reduce waste. It is important to consider recycling costs at the beginning of the project to ensure it can be covered during end-of-life. Recycling processes primarily target cathode-active materials and associated metal streams, which represent the highest-value components for material recovery. These streams may include lithium, nickel, cobalt, manganese, copper, and aluminum, with recovery efficiency depending on battery chemistry and the specific recycling process employed.

RECYCLING PATHWAYS

Recycling infrastructure is most mature for battery chemistries that have been produced at large scale for decades, such as lead-acid batteries used in vehicles and uninterruptible power supplies, and small lithium-ion batteries used in consumer electronics. While many of the underlying recycling processes are similar across battery types, large-format batteries used in stationary energy storage have different methods for collection, handling, transportation, disassembly, and regulatory oversight.^{7,8} Current lithium-ion and sodium-ion battery⁹ recycling pathways include:

- **Pyrometallurgical recycling**, which uses high temperature smelting to recover metals
- **Hydrometallurgical recycling**, which uses aqueous chemistry to separate and purify materials
- **Direct recycling**, which aims to regenerate active materials while preserving their structure

Pyrometallurgical and hydrometallurgical recycling processes are widely used for lithium-ion batteries with nickel- and cobalt-based cathodes, such as nickel manganese cobalt/nickel cobalt aluminum chemistries. Pyrometallurgical and hydrometallurgical are also expected to be applicable to sodium-ion chemistries with process adaptations. Direct recycling is still at pilot-scale for all these battery types.

Flow batteries differ from lithium-ion systems in that energy is stored in liquid electrolytes rather than solid electrodes. As a result, the potential for electrolyte reuse drives recycling considerations. The process involves collecting, filtering to remove contaminants (like Fe, Ni, Cu), and purifying the electrolyte to restore vanadium, with up to 97–98 percent recovery rates. Non-electrolyte components such as tanks, pumps, piping, and power electronics follow conventional recycling or disposal pathways similar to other industrial equipment.¹⁰

RECYCLING COST¹¹

Recycling typically represents the largest cost component of battery end-of-life management, exceeding costs associated with system disconnection, transportation, and site work. Recycling costs vary significantly by battery chemistry and are influenced by material recovery value and recycling process. Transportation and handling contribute to total costs but are generally secondary to recycling and processing costs. While some non-battery BESS components may have longer service lives or resale value, battery management remains the dominant driver of end-of-life cost. Developers may design BESS installations to enable battery replacement over the project lifetime, allowing non-battery system components to remain in service longer while battery modules are periodically replaced and recycled.

WASTE MANAGEMENT

Waste management addresses components that cannot be reused or recycled at the end of service life. Some materials and components may be non-recoverable because they are hazardous or without approved recycling pathways. Waste management activities are conducted in accordance with federal and state requirements, including the Resource Conservation and Recovery Act and applicable state-level hazardous waste regulations.

- ¹ Dai, Qiang, Jakob Elias, and Jeff Spangenberg. 2023. *“End-of-Life Considerations for Stationary Energy Storage Systems.”* DOE OE Energy Storage Peer Review Presentation 901. Sandia National Laboratories.
- ² Patel, Anisha N., Laura Lander, Jyoti Ahuja, James Bulman, James K. H. Lum, Julian O. D. Pople, Alastair Hales, Yatish Patel, and Jacqueline S. Edge. 2024. *“Lithium-ion Battery Second Life: Pathways, Challenges and Outlook.”* *Frontiers in Chemistry* 12 (April): 1358417. <https://doi.org/10.3389/fchem.2024.1358417>.
- ³ RSP Architects. 2025. *Battery Energy Storage Systems (BESS): Planning and Design Considerations*. April 2, 2025.
- ⁴ Khabur, Maxim. 2025. *“BESS Decommissioning and End-of-Life Planning: Why Care Today?”* *Power Magazine*, February 11, 2025.
- ⁵ Chen, Mengyuan, Xiaotu Ma, Bin Chen, Renata Arsenault, Peter Karlson, Nakia Simon, and Yan Wang. 2019. *“Recycling End-of-Life Electric Vehicle Lithium-Ion Batteries.”* *Joule* 3 (11): 2622–2646. <https://doi.org/10.1016/j.joule.2019.09.014>.
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PROJECTS WITH BESS

Battery energy storage systems (BESS) store electricity for later use and can rapidly charge or discharge in response to grid conditions. By providing energy during outages, reducing peak demand, and supporting grid operations, BESS can improve everyday reliability and increase resilience during extreme events. BESS deployments are increasing across the United States as costs have declined and the need for flexible grid resources has grown. Today, thousands of BESS are operating nationwide, ranging in size from small-scale local systems serving individual buildings or neighborhoods to large, utility-owned installations capable of supplying power at the regional level.

This factsheet presents examples of BESS deployments around the United States drawn from a Pacific Northwest National Laboratory (PNNL) report entitled, “Typical Use Cases for Energy Storage in Rural Areas.”¹ This factsheet also includes a summary of key BESS project elements.

PROJECT EXAMPLES

UNITED POWER COOPERATIVE: FIRESTONE, COLORADO

United Power Cooperative in Firestone, Colorado developed a 4 MW/16 MWh BESS project structured to deliver peak demand savings to its members (Figure 1). The battery charges when wholesale electricity prices are low and discharges during high price periods, which helps reduce the co-op’s exposure to market volatility.



Figure 1. United Power Cooperative’s Carbon valley battery storage facility.²

United Power anticipates savings of about \$1 million USD annually. Co-op members can benefit from these savings by participating in a subscription model that allocates portions of the battery capacity to participating customers. Members pay a fixed monthly subscription fee based on their subscribed capacity and receive bill credits that reflect the peak shaving value the battery provides. This is similar to how a residential battery system would reduce demand charges at an individual home.

HOLY CROSS ENERGY: GLENWOOD SPRINGS, COLORADO

Holy Cross Energy, a cooperative utility provider in Glenwood Springs, Colorado, partnered with Colorado Mountain College to deploy 4.5 MW solar photovoltaics (PV) and 5 MW/15 MWh BESS. Together the installation generates enough locally produced electricity to serve roughly 1,000 homes under typical conditions. The BESS enables the co-op to capture excess solar generation and discharge it during periods of peak demand, helping manage system loads and reduce reliance on natural-gas peaking plants.³ In this way, the system improves operational flexibility by shifting locally generated energy to peak times.

The BESS consists of 68 battery stacks housed in four on-site containers (Figure 2). Each enclosure includes an integrated heating, ventilation, and air conditioning (HVAC) system, humidity control, and fire suppression equipment to maintain safe operating conditions and safety standards compliance.

BLUE LAKE RANCHERIA TRIBE MICROGRID: BLUE LAKE, CALIFORNIA

In Humboldt County, California, the Blue Lake Rancheria Tribe operates a solar plus storage microgrid designed to maintain power to its campus during normal grid conditions and utility outages. The system combines a 420 kW solar PV array with a 500 kW/950 kWh BESS. Together they support



Figure 2. Solar panels and battery energy storage systems at Colorado Mountain College's Spring Valley Campus.⁴

Tribal administrative buildings, electric vehicle charging stations, a gas station, a hotel, and a casino.

The microgrid's value was demonstrated during a 2019 public safety power shutoff event when much of the surrounding area lost electricity. Although the broader grid was deenergized, the Tribe's campus continued operating and served as a community resilience hub. The microgrid provided critical services, including a safe, warm community space, cell phone charging and internet access, fuel delivery, and housing for people whose medical needs require access to electricity. During the outage, the microgrid served about 10,000 people (~10 percent of Humboldt County's population at the time) and was recognized for helping protect medically vulnerable individuals during the emergency. Figure 3 shows the major project components of the Tribe's microgrid.

NAVAJO TRIBAL UTILITY AUTHORITY: DILKON, ARIZONA

The Navajo Nation, spanning rural and remote areas of Arizona, New Mexico, and Utah, faces significant energy access challenges due to its geographic scale and dispersed population. As of 2024, 13,000 residents were estimated to live

¹ Moncheur de Rieudotte M.P. and J.R. Kerby. 2025. Typical Use Cases for Energy Storage in Rural Areas, PNNL-37841. Richland, WA: Pacific Northwest National Laboratory.

² United Power Cooperative. n.d. *Energy Projects*. <https://www.unitedpower.com/energy-projects#heading-accordion-3665-1>.

³ Holy Cross Energy. *Power+ Battery Program*. <https://www.holycross.com/member-programs/powerplus>. Accessed January 22, 2026.

⁴ Holy Cross Energy. *Colorado Mountain College Solar + Storage Project*. <https://www.holycross.com/our-system/renewable-energy/cmc-solar-storage>. Accessed January 22, 2026.

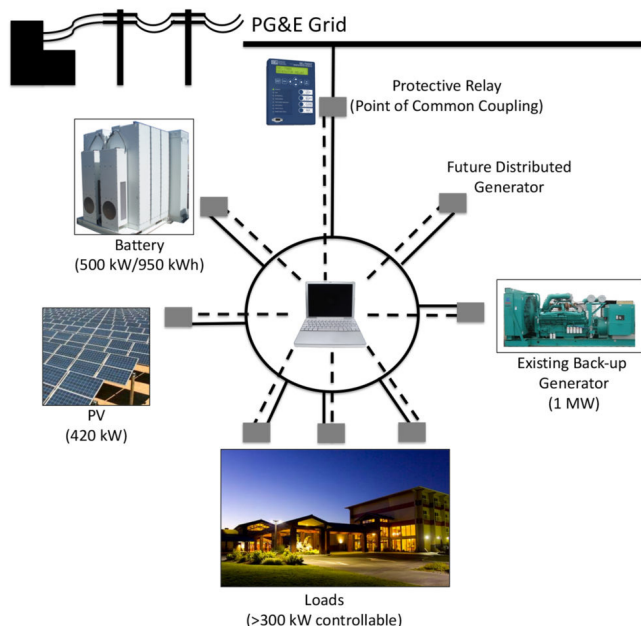


Figure 3. Major project elements of the Blue Lake Rancheria Tribe Microgrid.⁵

without power.⁷ This highlights a need for alternative solutions in areas where extending traditional distribution infrastructure can be cost prohibitive.

To explore off-grid energy options, the Navajo Tribal Utility Authority (NTUA), in collaboration with Sandia National Laboratories, deployed a small-scale demonstration system in Dilkon, Arizona in 2022. The project paired a 1.8 kW solar PV array with a 3 kW/13 kWh BESS designed to operate independently of the utility grid (Figure 4).

The system used a zinc manganese dioxide (ZnMnO₂) battery chemistry, which was selected as part of a broader effort to evaluate alternative storage technologies for residential, off-grid applications. By combining solar generation with on-site energy storage, the demonstration project provided reliable electricity to a home without requiring connection to existing transmission or distribution infrastructure. The project illustrates how distributed stand-alone systems may help address energy access gaps in geographically isolated communities.



Figure 4. Installed BESS and solar panels in Dilkon, Arizona.⁶

BESS Project Considerations

Site Layout

The examples in the past section highlight the range of ways BESS can support energy reliability, resilience, and access across diverse communities. This section summarizes key project considerations for BESS.

- BESS units are modular and are often housed in containers roughly the size of a 20-foot shipping container.
- Units are typically installed on concrete pads with or on paved surfaces.
- Sites generally include access roads, fencing, lighting, and nearby transformer and inverter equipment.
- At the utility scale, dozens to hundreds of these containerized units can be arranged in rows to meet large-scale energy storage needs.

⁵ Schatz Energy Research Center. *Blue Lake Rancheria Microgrid*. <https://schatzcenter.org/blrmicrogrid/>

⁶ Sandia National Laboratories. 2023. *Demonstration Projects Supporting Energy Access and Storage Innovation*. Albuquerque, NM: Sandia National Laboratories. https://www.sandia.gov/app/uploads/sites/82/2023/10/PR2023_104_Cowles_Gabriel_Demonstration-Projects.pdf

⁷ Ziv, Kristin, Daniel Cardenas, Richard Luarkie, Debabrata Chattopadhyay, and Morgan Bazilian. 2024. *Electricity Access in the Navajo Nation*. Golden, CO: Payne Institute for Public Policy, Colorado School of Mines. <https://payneinstitute.mines.edu/electricity-access-in-the-navajo-nation/>

- Community-scale systems are often smaller than utility-scale systems and may be sited near substations or behind buildings.
- Landscaping, adequate setback distances, fencing, and visual screening may be used to reduce visual impact.

Noise

- The main sources of noise at BESS facilities are cooling and ventilation fans, the hum from transformers and inverters, and operational sounds from the switchgear.
- At typical setback distances, sound levels are often comparable to common commercial equipment (e.g., rooftop HVAC units), rather than heavy industrial machinery.
- Systems can be designed to meet local noise ordinances through specific equipment selection, enclosures, sound walls, and appropriate setback distances.

Inside the Containers

- BESS enclosures house electrical, thermal, safety, and control systems.
- The units also typically include walkways, access doors, and control panels to support maintenance and inspection.
- Common internal components include:
 - » battery racks or battery modules
 - » Battery Management System electronics
 - » thermal management equipment (e.g., air conditioning, heat exchangers)
 - » monitoring, control, and communications hardware
- Safety features include ventilation, gas detection, fire detection and suppression, thermal isolation, and controlled venting mechanisms.

Additional Considerations

- Site preparation may include grading, drainage, concrete pads, and access roads.
- Utility interconnection may leverage existing transformers and protection systems depending on site conditions.
- Electrical integration often requires additional switchgear, protection coordination, metering, or communications to safely interconnect the BESS.
- BESS units typically include on-board control systems to monitor and manage their operation.
- Integration with site, utility, or operator systems (e.g., Energy Management System, Supervisory Control and Data Acquisition, communications) may be required depending on ownership and use case.
- Security measures may include fencing, lighting, cameras, and restricted access controls.
- Fire safety and emergency response should consider access clearances, fire suppression zones, and coordination with local fire departments.

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