2024 TECHNICAL UPDATE

Energy Storage Integration Council (ESIC) Energy Storage Implementation Guide

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Former ESIC chair, Eva Gardow (EPRI, formerly FirstEnergy), has demonstrated dedication from inception to execute the mission of ESIC. Past and present EPRI working group and task force leads include Miles Evans, Steve Willard, Joe Thompson, and Brittany Westlake. Additionally, without the tremendous administrative support of Eva Ulett and former EPRI staff, Ben Kaun, Giovanni Damato, Karen Larsen, and Lucy Cha, execution of ESIC would not have been possible. ESIC acknowledges the support of former student employees Christian Martinez-Ventura and Excellent Osunkoya.

Numerous other individuals and organizations have also played leadership roles in the development of subgroups and individual topic work products. These individuals are recognized specifically in the context of those work products.

ESIC consists of more than 2,500 volunteer participants from more than 850 organizations.

This publication is a corporate document that should be cited in the literature in the following manner: *Energy Storage Integration Council (ESIC) Energy Storage Implementation Guide.* EPRI, Palo Alto, CA: 2024. 3002030029.

ABSTRACT

Effective implementation of utility-connected energy storage requires recognition of factors to consider through the complete life cycle of a project. This report serves as a practical reference guide through initial planning, procurement, system deployment, operations and maintenance, and end of life. It provides a bridge between work performed by participants in the Energy Storage Integration Council (ESIC) and the practical concerns of stakeholders involved with energy storage project deployments. Development of this document was supported by the combined efforts of three ESIC task forces and includes contributions from utilities, energy storage vendors, integrators, and the research and consulting communities. Through direct discussion, web links, and citations, the report provides access to an up-to-date suite of publicly available resources and insights into ESIC's ongoing work in support of developing common approaches that advance its mission. This guide is suitable for engineers, project managers, researchers, potential owners, and deployment partners who are newer to energy storage industry. ESIC stakeholders with more experience in energy storage can refer to the updated ESIC resources and lessons learned summarized at the end of each section.

This guide is updated periodically and evolves with new ESIC publications and industry use of the document. ESIC is an open technical forum with a mission to advance the integration of energy storage systems, which is guided by the vision of universally accessible, safe, secure, reliable, affordable, and environmentally responsible energy.

Keywords

Energy storage
Deployment and integration
Planning
Commissioning
Operations and maintenance (O&M)
Energy Storage Integration Council (ESIC)

ACRONYMS AND ABBREVIATIONS

AHJ	Authority Having Jurisdiction
BESS	Battery Energy Storage System
BMS	Battery Management System
CAISO	California Independent System Operator
CEC	California Energy Commission
DER	Distributed Energy Resource
DERMS	Distributed Energy Resources Management System
DER-VET™	Distributed Energy Resource Value Estimation Tool
DOE	U.S. Department of Energy
DOR	Division of Responsibility
EOL	End of Life
EPC	Engineering, Procurement, and Construction
EPRI	Electric Power Research Institute
ESIC	Energy Storage Integration Council
ESS	Energy Storage System
FAT	Factory Acceptance Test
GADS	Generating Availability Data System
HMA	Hazard Mitigation Analysis
HVAC	Heating, Ventilation, and Air Conditioning
IT	Information Technology
NERC	North American Electric Reliability Corporation
NPV	Net Present Value
O&M	Operations and Maintenance
OEM	Original Equipment Manufacturer
NWA	Non-Wires Alternative
OT	Operational Technology
PCS	Power Conversion System

PV	Photovoltaic
RFI	Request for Information
RFO	Request for Offer
RFP	Request for Proposal
RFQ	Request for Quote
SCADA	Supervisory Control and Data Acquisition
SOH	State of Health
SOW	Scope of Work
StorageVET®	Storage Value Estimation Tool
T&D	Transmission and Distribution

ENERGY STORAGE IMPLEMENTATION GUIDE USER QUICK GUIDE

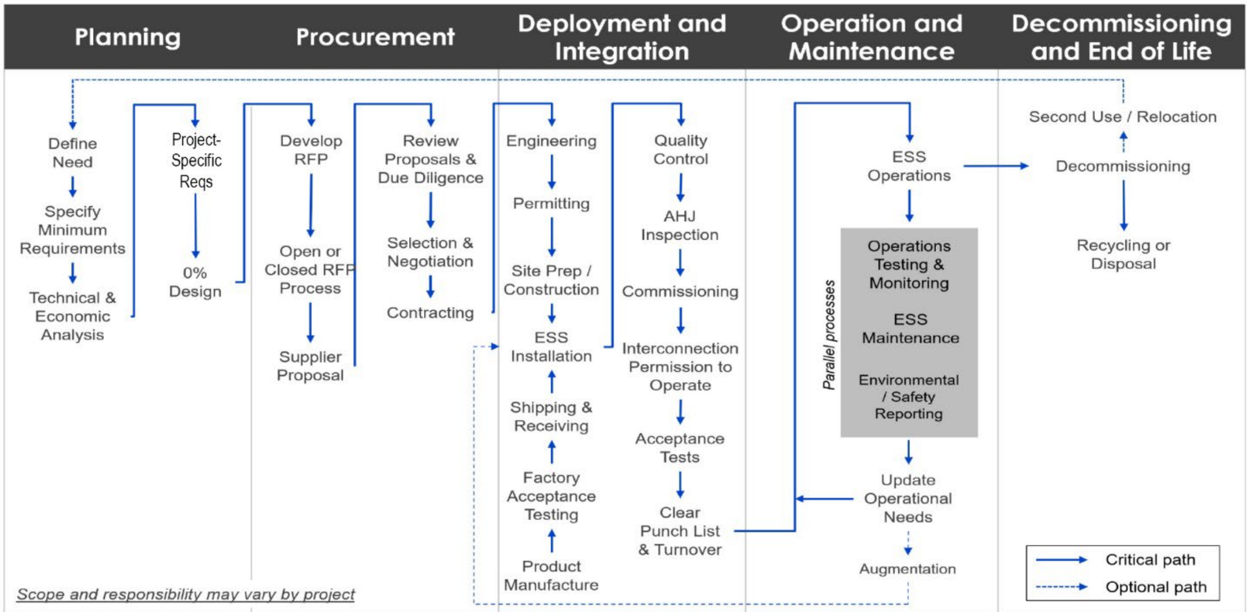
This quick guide provides a brief overview of the five chronological phases of the life cycle of an energy storage project as described in the *Energy Storage Implementation Guide*, including planning, procurement, deployment, operations and maintenance (O&M), and decommissioning. Many important items are hyperlinked to help users quickly navigate to specific content in the comprehensive implementation guide. This document is developed in close coordination with other Energy Storage Integration Council (ESIC) products, which can be accessed at www.epri.com/esic.

Section 1, Introduction, describes the purpose and organization of the implementation guide and an overview of ESIC.

The purpose of the ESIC Implementation Guide is as follows:

- To serve as an evolving reference guide for utility project managers, the suppliers they work with, and users investigating how to deploy safe, reliable, cost-effective energy storage solutions
- To identify and share common problems and risks that are encountered in the implementation of energy storage projects and provide a path toward resolution
- To provide ongoing updates on publicly available ESIC tools

To achieve these objectives, the guide is organized into sections that follow the five phases of the life cycle of an energy storage project. In each section, useful and publicly available tools, templates, and resources are referenced to guide users through each of those phases, with the goal of developing clear channels of communication within the project team, as shown in the figure below.



Section 2, Planning of Energy Storage, describes the process for identifying grid needs, technology selection translating such needs into technical requirements, and analyzing the cost-effectiveness and viability of energy storage projects.

Define Grid Needs

The first phase in the planning process for an energy storage procurement is the identification of grid needs to characterize applications and services. From the perspective of an electric utility stakeholder, there are several ways energy storage could be used to minimize, defer, or avoid costs; increase reliability; increase the operational efficiency of the electric power system; or support the adoption of renewable generation.

Specify Minimum Requirements

To compare energy storage technologies or with other potential solutions, requirements should be developed that are resource neutral and focus on the grid objectives or grid violations that are aimed to be corrected. After the minimum technical requirements for the grid solution have been defined, planners should note which parameters are important for an energy storage–based solution.

Perform Technical & Economic Analysis

At this part of the planning phase, there could be multiple options to meet grid needs, including conventional options. Decision makers may narrow the scope of options using a screening cost-benefit analysis. This analysis may include secondary service benefits and costs in addition to those associated with solving the primary service issues. A number of processes and tools may be helpful in performing a cost-benefit analysis including net present value (NPV), a metric that considers the net costs and net benefits of a new generator, and tools such as EPRI's Distributed Energy Resource Value Estimation Tool (DER-VET™) and Storage Value Estimation Tool (StorageVET®) products. DER-VET™ (www.der-vet.com) provides a free, publicly accessible, open-source platform for calculating, understanding, and optimizing the value of DERs based on their technical merits and constraints. DER-VET helps planners analyze the initial cost-effectiveness screen of available options.

Project-Specific Requirements

Elements for developing project requirements specific to energy storage include ownership of the storage asset, energy storage system (ESS) performance, communication and control system requirements, site requirements and availability, local constraints, and safety requirements.

Section 3, Procurement of Energy Storage, describes the phase of the project that turns previously defined minimum requirements from the planning stage into specifications that result in a formal request for proposal (RFP) or request for offer (RFO). The project team will then review the ESS proposals accordingly and evaluate how well individual proposed systems can meet project needs.

Develop RFP

A significant part of developing an RFP is development of the scope of work (SOW) for the project. The SOW is the process in which the utility, or the buyer, has the opportunity to define the project objectives and include specifications of the ESS, the energy storage product, balance of system, and other physical components and services required for complete project integration. The SOW should also clearly describe the expected responsibilities of each party for procuring, designing, and installing different project components. A detailed division of responsibility (DOR) matrix that supplements the RFP can clearly delineate responsibilities and interactions within each task. Additional ESIC guides and tools to support the development and clear communication of RFP requirements include the *ESIC Energy Storage Request for Proposal Guide* [6], *ESIC Energy Storage Cost Template & Tool v2.0* [42], *ESIC Energy Storage Technical Specification Template* [7], and *ESIC Energy Storage Safety: 2016, Guidelines Developed by the Energy Storage Integration Council for Distribution-Connected Systems* [41].

Review Proposals & Due Diligence

Proposal responses may include a broad spectrum of potential technologies and configurations. A well-formed RFP with established criteria for evaluating proposals can simplify the proposal review process. The ESIC Technical Specification Template allows the buyer to evaluate and compare technical specifications from potential bidders by requesting the same set of technical information within the same reporting format. Other evaluation criteria may include cost, prior deployment experience, financial stability, and other risk mitigation considerations.

Section 4, Deployment and Integration of Energy Storage, describes the stage after procurement contracting has been completed until the project has been installed, commissioned, and subsequently handed off to operations. To improve the estimates of time and cost required for implementation, it is important to address in detail the steps required at this stage.

Engineering	Site and system engineering will use contract technical specification requirements and utility and industry design codes and standards as the basis of design.
Permitting	It is important to engage local authorities having jurisdiction (AHJs) to understand permitting requirements and additional codes and standards applicable for the construction and operation of an ESS. Due to gaps in standards for energy storage with respect to codes, standards, and regulations and the lag time for AHJs adopting new ones, there may be a need to educate and discuss concerns and requirements for safety, nuisance, or environmental issues with certain departments within an AHJ.
Site Preparation/ Construction	After a permit or notice to proceed with construction is issued, site preparation and construction can begin.
Product Manufacture and FAT	When the product manufacturing and build is complete, it is a common practice for the utility or a third-party to witness a factory acceptance test (FAT) at the vendor's manufacturing facility prior to shipment. The FAT is typically a set of quality control-related tests to help ensure that ESS components, including the integration, have been built to specifications.
Shipping and Receiving	After the ESS is approved for shipment, it is transported to the site. Responsibility for product shipping and receiving procedures, loading and unloading equipment and practices, and modes of transportation should be determined during procurement.
ESS Installation	ESS product installation and system integration can be performed by an electrical contractor who should be experienced in both high- and low-voltage systems and familiar with the local electric utility system. However, contractors may be unfamiliar with ESS technology and require sufficient training and documentation to ensure they understand ESS safety hazards and procedures.
Commissioning	Following installation of an ESS, commissioning is required to ensure successful integration. EPRI's ESIC Energy Storage Commissioning Guide [15] provides details of commissioning and site acceptance tests during the deployment and integration phase. A "punch list" should be maintained to enumerate open items to be addressed before the system can be deemed commissioned.

Interconnection	Before the ESS is allowed to interconnect with the grid, tests and documentation may be required to ensure compliance with interconnection standards.
Acceptance Tests	Additional performance and control functionality tests may be required to verify that the system operates as expected. The *ESIC Energy Storage Test Manual* [4]—with its detailed test protocols that include measurement and calculation methods, testing duty cycles, and templates for data collection—can be used for acceptance testing.

Section 5, Project Operations and Maintenance, provides an overview of the process steps required over the system operational life. Because many planning assumptions for the project may evolve over time, it is important to consider both current and future needs while assessing the inherent strengths and limitations of energy storage technology.

Handoff to System Operations	During handoff, grid and energy resource operators as well as other parties with control of the storage system are well-informed and trained regarding the storage system operational software, intended use of the product, protection systems and schemes invoked, planned operational profile of the storage system, and safety plan.
ESS Maintenance	Maintenance of any asset comes in two forms: preventive and corrective. Preventive maintenance may be scheduled relative to time, determined based on level of usage, or triggered based on monitoring or performance data and other factors including environmental conditions. Corrective maintenance is typically costlier because it may require unanticipated service calls or prolonged loss of service. Depending on the technology and use case, there may also be a need to augment the energy capacity over the life of the project.
Environmental / Safety Reporting	Depending on the type and size of the storage system used, there may be an ongoing requirement to report chemical content, operational status, and other parameters to AHJs.
Update Operational Needs	If changes in operational needs are identified, modeling and simulation efforts could help to understand both the future demand and the current ESS operating needs. Changes in operation outside the warranty provision or agreed-upon use case may need to be discussed with the vendor or supplier.
Recommissioning	Situations involving replacement of major system components, which could include firmware updates and changes in operation outside the original scope, may require system recommissioning. In addition to recommissioning, periodic performance testing may be conducted to ensure warranty compliance or to document performance over time.

Section 6, Decommissioning and End of Life, describes the consideration of issues during the last phase of the project life cycle when the system is no longer viable. End of life (EOL) can be expected by a predetermined project end date, triggered by safety or reliability issues, or caused by exceeding marginal costs relative to marginal benefit. A well-defined EOL condition for the ESS project can ensure project safety, reliability and cost-effectiveness.

Decommissioning	Decommissioning costs and specifications should be considered throughout the life cycle. When the owner decides to decommission an ESS, a comprehensive decommissioning plan should be prepared to ensure a safe, efficient process.
Recycling/ Disposal or Relocation	As part of the decommissioning plan, it should be determined what will happen to the system after it leaves the site. A plan could be made to recycle and dispose of the system components or, if there are components that have useful life, they could be reused at another location.

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1 INTRODUCTION

Purpose of This Implementation Guide

This guide is intended to accomplish the following:

- To serve as an evolving reference guideline for utility project managers, the suppliers they work with, and users investigating energy storage solutions, particularly those new to the energy storage industry.
- To identify common problems and risks that are encountered in the implementation of energy storage projects and provide considerations.
- To provide references to other publicly available guides and tools of the Energy Storage Integration Council (ESIC).

Organization of This Guide

The objective of this document is to guide readers through the five phases of the life cycle of an energy storage project, referencing publicly available tools, templates, and other resources along the way. As shown in Figure 1, the five chronological phases of the life cycle in this implementation guide are planning, procurement, deployment and integration, operation and maintenance, and decommissioning.

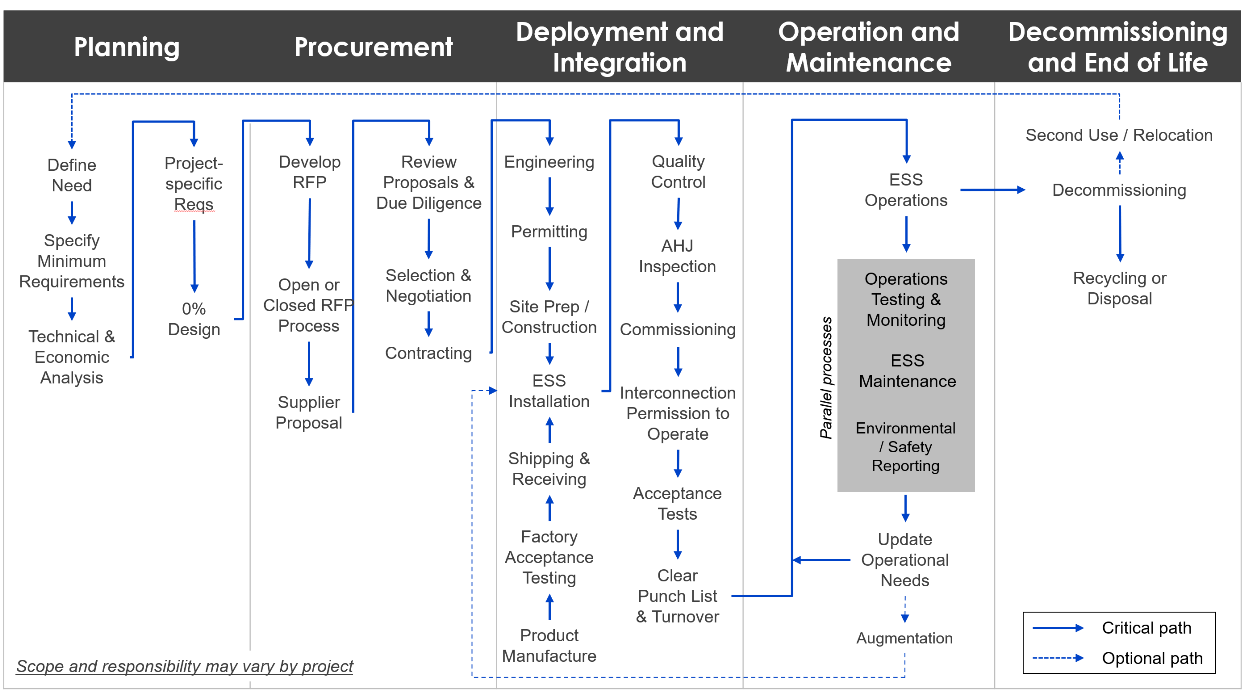

Figure 1. Project life-cycle phases summary

This guide is organized according to these life-cycle phases, with the section contents as follows:

- **Section 2, Planning of Energy Storage:** This section begins by looking at potential opportunities for energy storage systems (ESSs) through the lens of grid issues and needs. It discusses both traditional issues and emerging needs and then guides readers through the process of defining an ESS application and its requirements. Subsequent subsections introduce product cost-effectiveness analyses. This section concludes with discussion of on-site assessments for ESSs as well as frameworks, methods, and tools for conducting technical feasibility and impact assessments.
- **Section 3, Procurement of Energy Storage:** This section begins with a detailed look at developing a request for proposal (RFP) and the associated technical specification for the solution requested. It provides details on different considerations to include in the specifications and then discusses the evaluation of supplier proposals. The section concludes with a subsection on conducting detailed technical and business case analyses and contracting.
- **Section 4, Deployment and Integration of Energy Storage:** This section walks readers through each step of deploying an ESS. It covers a broad range of topics—from required departments and specific roles to site engineering, product acceptance testing, logistics, installation, and commissioning.
- **Section 5, Project Operations and Maintenance of Energy Storage:** This section discusses project operations and maintenance (O&M) considerations throughout the operational life of an energy storage project.
- **Section 6, Decommissioning and End of Life of Energy Storage:** This section discusses considerations that define the end of life (EOL) for energy storage projects and for decommissioning an energy storage project.
- **Section 7, References:** This section lists references cited in the main sections of this guide. Additional references for ESIC focus areas can be found in the appendices associated with them.
- **Appendix A:** This appendix provides a list of acronyms and abbreviations used throughout this guide.

Overview of the Energy Storage Integration Council

This section provides a brief overview of the ESIC to highlight the importance of common approaches and terminology and to describe the process by which ESIC tools, guides, and templates are developed. For additional information on how ESIC operates, visit www.epri.com/esic.

Energy Storage Integration Council Mission

ESIC's mission is to advance the integration of ESSs through open, technical collaboration, guided by the vision of universally accessible safe, secure, reliable, affordable, and environmentally responsible energy.

ESIC is an open, technical forum that facilitates conversations between energy storage stakeholders, including utilities, developers, the research community, regulators, and the public to address technical and operational issues associated with deploying ESSs. For more than 10 years, EPRI convened and coordinated ESIC's working groups (now called focus areas driven by task forces) and strategic sessions in order to publish documents and online resources. Council participants worked together through meetings, webcasts, and teleconferences to identify areas of common interests and concerns and to share deployment experience. ESIC collects, develops, publishes, and shares information on leading practices that support effective energy storage integration through a variety of guides and tools. ESIC guides considerations of multifaceted strategies and requirements for energy storage to provide value to the grid, while maintaining safety and reliability. The ESIC forum is also a platform to discuss emerging issues and to review and provide input to efforts by other organizations that support ESIC's mission.

Energy Storage Integration Council Collaborative Process

Figure 2 illustrates ESIC's working process:

- Identify strategic gaps in understanding of technical requirements for ESSs along with current deployment concerns.
- Define work products or ideas to address the gaps in areas such as handbooks, guidelines, software, webcasts, or others.
- Task forces work collaboratively and tactically with ESIC to develop tools and guidelines, which are reviewed, published, and distributed to provide common understanding among utilities, solution providers, and other stakeholders.
- Work products are updated as new information becomes available or industry needs arise.

Figure 2. The ESIC collaborative process

At the end of this process, EPRI endeavors to publish work products developed through ESIC, which are made available to the public for free. Work products developed outside ESIC may be periodically reviewed in both draft and final forms by ESIC. The entities that develop these products typically publish them using their own resources. However, reviews of these documents may become ESIC work products. In addition, portions of externally developed work products may be referenced in ESIC documentation, as coordinated with the responsible party.

Energy Storage Integration Council Focus Areas

ESIC currently has three focus areas, which were formerly known as working groups: Grid Services, Testing and Characterization, and Grid Integration, as shown in Figure 3. ESIC is organized in these three topic-focused areas, where task forces within each area drive the development of specific work products and coordinate to define common approaches to the development and use of safe, reliable, cost-effective energy storage.

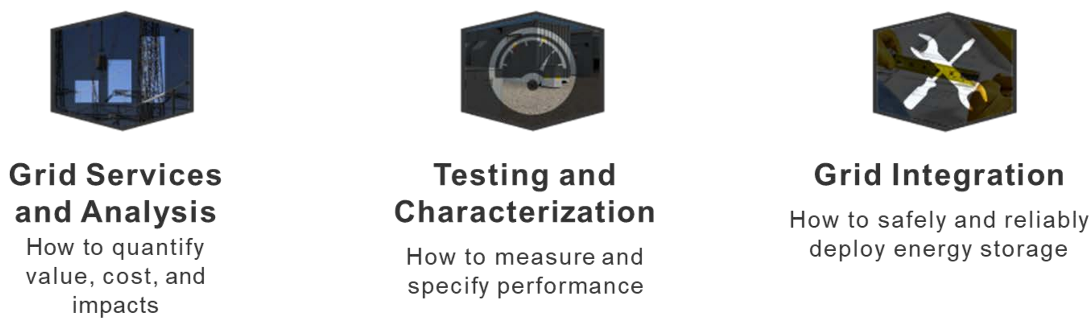

Figure 3. ESIC focus areas

The mission of the Grid Services and Analysis task force is to determine the requirements of energy storage to solve grid needs, provide value, and develop guidelines and definitions for analysis of ESS value and impacts on the power system. The task force provides practical methods for identifying relevant solution requirement parameters as well as ESS requirements for energy storage. Under this area, common definitions are developed for energy storage technology models, grid services requirements, and benefit calculations. This task force is the venue through which the industry provides guidance to EPRI-led projects, including ones funded by the California Energy Commission (CEC), to develop publicly available distributed energy resources (DERs) and energy storage valuation tools such as the Distributed Energy Resource Value Estimation Tool (DER-VET™) and Storage Value Estimation Tool (StorageVET®).

The mission of the Testing and Characterization task force is to consistently define the technical characteristics of fully integrated energy storage products relevant to utility requirements. This entails identifying common terminology and definitions for energy storage product performance and technical characteristics. It also involves defining or facilitating the creation of test procedures to consistently verify energy storage characteristics for lithium ion batteries and emerging technologies.

The mission of the Grid Integration task force is to provide practical guidance for the implementation of energy storage in the field, with the goal of providing utility project deployment and integration guidelines. This entails procurement, commissioning, communication and control, cyber security, and safety guidelines

2 PLANNING OF ENERGY STORAGE

Introduction to Planning

This section covers the first phase of energy storage project implementation: planning. This phase begins with the identification and definition of the grid or customer needs and translates those needs into requirements. The objective is to provide an analytical framework on which to base a decision of whether to proceed with an energy storage procurement project.

The planning process for energy storage requires an understanding of the current process and a detailed evaluation of power system needs, criteria, and alternatives as well as an overall cost-benefit analysis.

Planning an energy storage procurement project involves the following steps:

- **Defining** the problem and **assessing** whether storage may be a good fit
- **Specifying** minimum solution requirements to solve the problem
- **Evaluating** the technical feasibility and cost-effectiveness of storage
- **Finalizing** case-specific requirements of storage

The planning process is often referred to as *developing a use case.* The use case framework can support a system planner by helping to identify the technical objectives, the elements (such as personnel and devices), and their step-by-step interactions as a project moves toward implementation. Use cases can be general or highly detailed.

Beyond site-specific planning and use of energy storage, some utilities are considering energy storage for both transmission and distribution (T&D) system applications, ranging from targeted system-wide deployment levels as part of regional goals or mandates to customized applications such as a non-wires alternative (NWA). For systemwide deployments, planners require comprehensive and systematic analysis approaches to identify and evaluate the efficacy of energy storage applications. Ongoing EPRI research aims to develop a systematic approach, analytical methods, modeling requirements, and gaps to evaluate targeted systemwide deployment opportunities in a robust and comprehensive manner. To support the planning, ESIC has compiled a bibliography of reports and papers focused on the operational, planning, and economic analysis of energy storage technologies [1].

Define the Problem and Assess Storage as a Solution

The first step in the planning process for an energy storage project is to identify the needs and determine whether storage may be a solution. Project planning assessments can begin by asking the following questions: 1) What is the primary service and secondary service? and 2) Is energy storage an option for addressing this need?

From the perspective of an electric utility stakeholder, energy storage could be used in several ways to minimize, defer, or avoid costs; increase reliability; or increase operational efficiency of the electric power system. There are both fixed and variable costs inherent to generating, transmitting, and delivering safe and reliable electric power. Factors affecting these costs include the following:

- Load growth-driven T&D capacity investments
- Load growth-driven generation capacity investments
- Renewable-driven T&D capital investments
- Contingency-driven T&D capacity investments
- Bulk system operations (energy and ancillary services)
- Local power quality and reliability issues

In addition, a number of emerging drivers have resulted from the adoption of both fossil and renewable distributed generation by utilities, utility customers, and third parties as well as the overall drive toward a more environmentally responsible electric power sector. These include the following:

- Distribution feeder-level photovoltaic (PV) hosting capacity limitations
- Distribution-level resiliency to weather (and other contingency) events, enabled by DERs
- Renewables ramping and aggregated impact on bulk electricity needs for flexibility
- Decarbonization of the grid and energy storage targets or mandates

Specifying Minimum Solution Requirements

An important initial step is to define the grid services and the specific required impacts to achieve a solution. To begin, planning criteria must be identified and quantified, first accounting for the scope and time frame for stakeholder decision making. Planning scenarios should be developed to study the problem of interest, including the study year, future load growth, generation mix, and sensitivities. Possible concerns or violations to operation, such as exceeding normal or emergency load rating, should be identified and characterized through an analytical method appropriate for the domain and issue. Finally, from characterized violations, the technical impacts to correct a violation may be derived. Solution requirements should be *resource neutral*, that is, not specific to one type of energy storage or even energy storage in general. For example, in a case in which capacity limits of distribution assets are exceeded in the planning horizon, solutions requirements would include, at a minimum, the capabilities of power, energy, and availability for the energy storage (or other) resource to maintain the asset below its peak load limit. The phases described for defining grid services are illustrated in Figure 4.

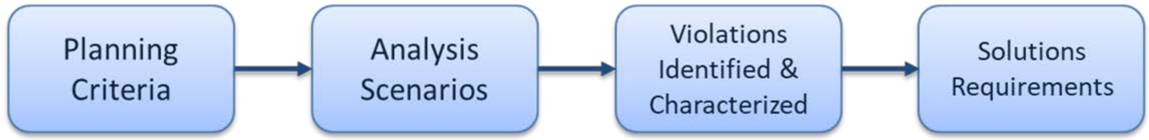

Figure 4. Defining grid services (technology-neutral solution requirements)

The process of defining grid services can be relatively straightforward on a conceptual level, but to define grid services driven by emerging grid needs, planners and operators need supporting methods, models, and data to assess standard modes of operations, exceptions, violations, and the resulting solutions and/or requirements. Additional grid service definitions are applied in the DER-VET and StorageVET modeling tools [2, 3].

In practice, the array of options under consideration should first be evaluated and screened according to their ability to provide a solution and meet other compliance criteria. When the options under consideration do not appear to provide a solution, it can be worthwhile to reassess the options, bearing in mind that new technologies might not fit into existing solution categories. As a framework, there could be two broad categories of feasible technology and service combinations, such as the following: 1) conventional utility options such as generators, wires, transformers, voltage regulators, capacitors, protection equipment, and feeder reconfiguration and 2) alternative options such as storage, load flexibility, smart inverters, distributed generation, hybrid solutions, and microgrids.

After the minimum technical requirements for the grid solution have been defined, planners should note which solution parameters are important in the context of an energy storage-based solution. For example, it would be important to consider the expected load shape and load growth rate of a distribution feeder to understand how much power and energy a storage solution would need to support a given transformer or circuit on the highest peak day to maintain reliability under the planning criteria. This approach contrasts with historical approaches that may dictate a need to specify a transformer upgrade, reconductoring, or other "wires-based" solutions, which do not take into account the peak duration requirement.

Evaluating the Technical Feasibility and Cost-Effectiveness of Energy Storage

To identify the best solution, decision makers may further narrow the scope of options using screening technical feasibility and cost-benefit analyses.

A technical feasibility screening will confirm whether the storage solution is able to solve the problem or if the minimum storage requirements need to be adjusted. The analysis will also identify any potential negative impacts to the grid and subsequent constraints on the use of storage to mitigate any impacts.

The cost-benefit analysis may include "secondary" service benefits and costs in addition to those associated with solving the primary service. The scope of benefits considered in the analysis could be restricted by regulatory or business model considerations; however, it is important to note the potential evolution of regulatory, policy, and business models over the life of a long-term asset. Options may have different sets of potential benefits to consider, depending on the owner, location, and technology capabilities. These benefits can be considered in addition to a purely cost-based analysis, which is the historical approach for the distribution planning process with “wires-only” solutions.

Analyses of NWAs are often compared with use of the conventional utility alternative that is based on solution requirements only. However, it is increasingly necessary to expand the scope of the analysis to incorporate requirements specific to emerging options, which often contain strengths and limitations similar to energy storage, such as location-specific benefits, limited duration, or fast response. The ability to address grid services varies by resource and could be most reliably and cost-effectively addressed by a combination of resources.

Net present value (NPV) is a process for considering non-reliability benefits in the procurement of generation for resource adequacy or capacity. NPV assesses the profitability of investing in a battery storage system by comparing the present value of expected cash inflows and outflows (such as revenue from energy sales, cost savings, and operating costs) against the initial investment cost. The NPV considers the time value of money, recognizing that a dollar received today is worth more than the same dollar received in the future. If NPV is greater than zero, the project is financially viable as the investment generates more value than its cost. Similar analytical approaches are needed to consider the full potential scope of both economic and reliability benefits of energy storage and other DERs.

Funded by the California Energy Commission (CEC), DER-VET™ provides a free, publicly accessible, open-source platform for calculating, understanding, and optimizing the value of DERs based on their technical merits and constraints [2]. An extension of EPRI’s StorageVET® tool [3], DER-VET supports site-specific assessments of energy storage and additional DER technologies—including solar, wind, demand response, electric vehicle charging, internal combustion engines, and combined heat and power—in different configurations such as microgrids. DER-VET and StorageVET are both publicly accessible and currently used tools for value estimation of various DER technologies, including ESSs. EPRI’s analysis team is using ESIC as a venue for industrial guidance on modeling energy storage use cases and technology. Common approaches to methods, models, and data requirements for energy storage are under development in the ESIC Grid Services and Analysis focus area. As a result, the DER-VET and StorageVET task forces strive to address stakeholders’ challenges and incorporate a common modeling approach in the analysis infrastructure.

Identifying and Assessing Specific Requirements of Storage

The process for developing detailed energy storage-specific requirements has progressed for some but is limited for others when deploying large-scale utility ESSs. At this stage, it is important to identify and document relevant considerations for establishing requirements of energy storage products and implementation as well as enabling infrastructure for validating the asserted value and applications. Several elements for developing energy storage project requirements are illustrated in Figure 5.

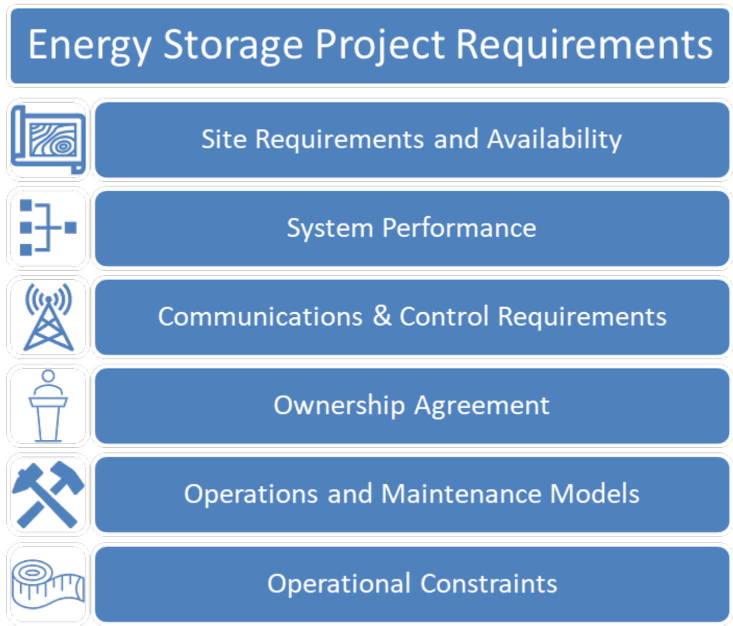

Figure 5. Energy storage project requirements

These required solution elements are interrelated, dependent on specific locations, jurisdiction, and system owners. The order of operations may depend on the scope of consideration and control for the decision-making stakeholder(s) as well as degrees of freedom for the analyses. For example, the storage controller requirement may be substantially different between a system that is integrated with a utility's distributed energy resource management system (DERMS) as compared to a case in which the utility does not have any grid edge monitoring and control. The space requirements could be dependent on the products available and clearances as described by codes and standards adopted by the authorities having jurisdiction (AHJs). The ownership and O&M agreements depend on the asset management models desired by the energy storage owner.

Ownership of the Storage Asset

As part of the definition of technical requirements, a key initial step is to determine and assign ownership of the storage system. Systems can be owned by the utility or by a third party, that is, an independent power producer, from which only services or capacity are purchased. This is a crucial step in that downstream requirements and specifications can vary depending on ownership. Even if the utility owns the asset, it could be managed through another business unit in transmission, distribution, or generation. A case in point would be the infrastructure and interconnection requirements. For example, a storage system assigned as a substation asset may be constructed, controlled, and operated differently than one designated as a distribution asset. Ownership designation must also be considered from a broader, forward-looking standpoint in terms of placement of multiple units and a growing emphasis on distributed technologies in general. Additional considerations affected by the ownership decision include regulatory delineation, asset financial classification within the utility accounting system, warranty enforcement, site access, maintenance assignment, response to alarms, storage disposition, and energy storage equipment removal or relocation, to name but a few.

Energy Storage System Performance

When defining storage technical characteristics, it is important to have consistent terminology and definitions. ESIC has developed a Technical Specification Template to support clear and consistent communication of function and performance parameters. In addition, benchmarks for reporting ESS performance have not been consistent, so ESIC has been working to develop a common measurement method and a set of compliance tests. EPRI's *Energy Storage Integration Council (ESIC) Energy Storage Test Manual* [4] includes testing protocols for characterizing performance metrics and validating functional requirements.

Communication, Control, and Cybersecurity System Requirements

Requirements documents can ultimately establish the framework of the intended communication and controls for storage projects—key to successful commissioning and downstream operation. These efforts are nontrivial, as they require coordination with many internal stakeholders to ensure that legacy systems interface with new distributed systems in a robust, cost-efficient, and secure manner. The framework—depending on the complexity of what is required from the storage system—needs to detail specific system and user requirements. Successful integration of storage often hinges on upfront analysis and documentation as well as pre-commissioning testing of the requirements in a prescribed documentation effort, similar to an information technology (IT) requirements document. Cybersecurity requirements are continually evolving and depend on the type of interconnection, meaning that critical infrastructure and bulk power systems have stricter requirements than smaller islanded systems. Some policies restrict virtual or physical access from certain regions or countries. Identification of communications, control, and cybersecurity requirements and functional definitions are in progress in the Grid Integration focus area. EPRI's *Energy Storage System Taxonomy of Operating Behaviors: Third Edition* [36], defines a foundational number of operating principles and use cases for distribution-connected ESSs—in particular, those associated with grid-tied, islanded, and dispatched use cases. ESIC's cybersecurity gap analysis and risk assessment provided some background and outlined challenges to cyber security requirements for storage.

Site Requirements and Availability

Some considerations when siting a system may include space requirements, type of location (such as rural, residential, urban, commercial, or industrial), safety, applicable codes and standards, existing interconnection infrastructure, proximity to emergency response, permitting, physical access requirements, equipment clearance requirements, noise, appearance, or community outreach. An important consideration is zoning, which is a significant and challenging risk to manage, as it encompasses permitting, noise, appearance, and community outreach. Zoning personnel, AHJs, and code enforcement agencies need to be consulted as they can prevent construction from taking place. Other considerations include access to communication infrastructure, constructability, the ability to receive and place equipment, safety codes, emergency response, timing of siting, and access to maintenance activities. Additionally, the added costs for maintaining a remote site should be considered, including site security access, as some sites can be critical infrastructure that can significantly limit access to outside personnel.

Operational Constraints

Robust analyses should be performed to assess operational considerations, such as hosting analysis, production cost modeling to understand how a storage operation is expected to impact the larger system, and determination of whether there are constraints to operation that would inform the specification. Examples of operations specifications include ramp rate control, scheduling and scaling charge and discharge, and firming or smoothing activities for hybrid resources.

Request for Information

After defining and assessing storage-specific requirements, a request for information (RFI) can be issued to understand the available storage technology that satisfies the project's needs. Responses can give insight as to whether a solution is likely to meet space, schedule, or minimum technical requirements. In addition, energy storage products are now emerging with varying levels of technical readiness and independent evaluation. To screen the readiness of a technology, utilities may request a summary of experience or a list of field deployments with use case descriptions as part of an RFI. For technologies without extensive field data to reference, some utilities are performing demonstration or test projects to evaluate the storage products in terms of performance and compliance to safety and other relevant standards. EPRI's *ESIC Energy Storage Request for Proposal Guide* [6] can be used to support RFI development.

General Considerations: Team Building, Participation, and Utility Department Roles

Early in the project, it is important to communicate and evaluate requirements with a broad set of internal stakeholders. Utilities with energy storage deployment experience have highlighted the importance of early buy-in, training, and documentation for the different utility departments and roles. The first step of getting buy-in is clarification of which specific stakeholders are responsible for the decisions pertaining to regulatory and environmental compliance, safety, permitting, integration, operation, and planned and unplanned maintenance. Utility stakeholders and their respective areas of concern should be identified along with key concerns or interests they may have regarding a new energy storage project. Stakeholders from utility IT and operational technology (OT), field communications, system operations, metering, substations, protection and design, among others, could have key roles, and significant outreach to all parties is required.

It can also be beneficial to engage external stakeholders such as AHJs and community members at this stage of the project to clarify who needs to be involved in the project and any requirements that could potentially impact design or schedule.

Stakeholder engagement and interaction will become more uniform as energy storage is more widely deployed and integrated into standard utility practices. However, in the near term, it will be important to understand and precisely define the roles for each stakeholder.

Energy Storage Planning Lessons Learned

Included here are lessons learned that were gathered in EPRI projects, conferences, publicly available case studies, and submitted through an ESIC survey (Table 1). Inclusion in this report does not signify a recommendation from EPRI.

Table 1. Energy storage planning lessons learned

Category	Challenge and Impact	Lessons Learned
System Performance	Lack of consistent terminology use in reference to nominal vs. nameplate capacity.	Nominal capacity is the theoretical maximum value, while nameplate capacity is the guaranteed value at EOL.
Interconnection	A developer's interconnection approval was delayed due to the utility's lack of modeling capability for energy storage needed to perform a system impact study.	For project developers, account for project delay in interconnection process. Begin engaging with utilities early to provide accurate information to support modeling.
Specifications	During development of a project, there were multiple changes in site selection due to technical, cost, and customer profile assumptions being made.	Detailed planning is required for the site selection of a storage project. For utilities, key lines of business that must be involved include distribution planning, real estate, corporate communications, distribution line technicians, and supply chain.
Data/ Specifications	A utility's existing storage and DERs did not have all the relevant data needed for modeling the hosting capacity analysis.	Make sure data required to conduct a hosting capacity analysis are outlined early in the project and made available to the system owner.
Economic Modeling	A utility's project was eventually blocked by the utility's board because they could not prove the benefits of installing storage. The modeling software only showed the battery as a "price taker," and there was no way to get full credit for the cost of the simple-cycle peakers they were going to displace.	It is important to represent the benefits of energy storage for project approval. Representing these benefits can require specialized models to accurately illustrate the impacts of a project. Retirement projects could require product cost modeling of the future resource mix to understand the full operation commitment and costs going forward. Price taker models should be used with the limitations in mind, as larger storage systems can impact the

Category	Challenge and Impact	Lessons Learned
		system operation, and thereby prices, differently.
Communications / IT	Limited bandwidth available in the controller area network bus between the power conversion system (PCS) and battery management system (BMS), coupled with cybersecurity concerns that restrict remote data communications and logging, led to inadequate historical operating data to support battery defect warranty and performance guarantees.	Develop a consistent data communications and logging plan that aligns with the terms of the battery purchase agreement to ensure sufficient historical data for warranty and performance guarantees.
Auxiliary Systems – Heating, Ventilation, and Air Conditioning (HVAC)	Heating concerns in terms of HVAC planning for a building-based ESS considered the system needs at commercial operation date but did not adequately consider future needs as battery performance degrades and augmentation is needed.	Consider thermal management design/requirements throughout the life of the system, including potential augmentation.

Energy Storage Planning Resources

ESIC and EPRI provide a range of helpful resources for energy storage project planning, as outlined in Table 2.

Table 2. Useful resources for energy storage planning

Resource	Application in Planning
ESIC Energy Storage Technical Specification Template, Version 4, 3002030031, 2024 [7]	Provides a template and list of technical requirements for energy storage systems.
Energy Storage Cost Metrics: Exploring the Usefulness of "Levelized Cost of Storage" and Other Metrics, 3002028562	Provides considerations for different cost metrics related to energy storage
Long Duration Energy Storage Use Cases: A Primer on Defining Applications to Aid in Technology Selection, 3002030919	Describes different use cases for long duration energy storage and potential technology selection parameters
Energy Storage Integration Council (ESIC) Energy Storage Test Manual [4]	Provides insights on recommended testing for storage systems
ESIC Energy Storage Request for Proposal Guide [6]	Describes how to use elements of RFP template to support creation of RFI
Common Functions for Smart Inverters: 4th Edition [5]	Lists inverter functional requirements based on use case
DER-VET and StorageVET [2,3]	Publicly available tools for cost-benefit analysis, sizing and design optimization; used to confirm storage and DERs can meet general solution requirements
Energy Storage Analysis Supplemental Project Report: Finding, Designing, Operating Projects, and Next Steps (2018-2021) [8]	Methodology, case studies, and lessons learned concerning an energy storage analysis framework for site-specific energy storage technoeconomic valuation
Framework for Transmission Energy Storage Modeling and Planning [9]	Provides an overview and summary of a regional scope, data needs, and tools for storage integration
Battery Energy Storage Lifecycle Cost Assessment Summary: 2020 [10]	Discusses installed costs, O&M costs, and decommissioning costs for lithium ion batteries that can be used for screening analyses
ESIC Energy Storage Commissioning Guide [15]	Includes commissioning-related considerations during the planning phase
(reference 36) Energy Storage System Taxonomy of Operating Behaviors: Third Edition. EPRI, Palo Alto, CA: 2023. 3002027416.	Discusses common operating behaviors and language for energy storage functions.

3 PROCUREMENT OF ENERGY STORAGE

Introduction to Procurement

The procurement phase of energy storage implementation begins after the planning process yields a set of requirements for an energy storage project, which may include selection of specific technologies, sizes, locations, and capabilities. The procurement process will depend on the specific needs and requirements of the utility. The general steps of the procurement process are described in some detail below.

Development of Request for Proposal or Offer

The first step of procurement is for the customer—in this case, an electric utility—to align the defined storage requirements to the procurement vehicle, whether it is an RFP or a request for offer (RFO). In this document, however, the approach is assumed to be an RFP. It is important that whatever solution is requested can meet all the requirements to attain the desired value and to ensure that the solution does not create negative side effects or fail to comply with other requirements.

In addition to the technical requirements developed during the planning phase, more detailed specifications and requirements must be defined for an RFP. As mentioned in the planning section, to further develop those specifications, it is important to determine the ownership of the storage system. Both utility-owned and third-party owned structures—such as a power purchase agreement (PPA)—may be viable options for addressing grid needs with energy storage. There may be substantial differences in the information requested in an RFP issued under each of those two ownership scenarios.

EPRI's *ESIC Energy Storage Request for Proposal Guide* [6] details key elements to include in a solicitation. Due to the evolving nature of energy storage projects, special attention should be focused on the scope of work (SOW) and technical specifications. These are discussed in the following subsections.

Scope of Work

Understanding the full SOW for an energy storage project is an important component of the utility RFP. In the SOW, the utility can determine and define the parties responsible for procuring and installing specific portions of the project, illustrating what a supplier or a third-party vendor would be accountable for. This SOW may include the energy storage equipment, balance of system, and other physical components and services required for complete project integration. The SOW must be as specific as possible, detailing the demarcation point for all wiring, including controls, power, and auxiliary power. Timing considerations must be documented so that the project installation proceeds without interference between different parties working at the site. In addition, there is increased focus on end-of-life recycling and repurposing, and RFPs are increasingly requesting information about these topics.

The requested SOW may include both equipment and services associated with a fully integrated solution, as illustrated in Figure 6.

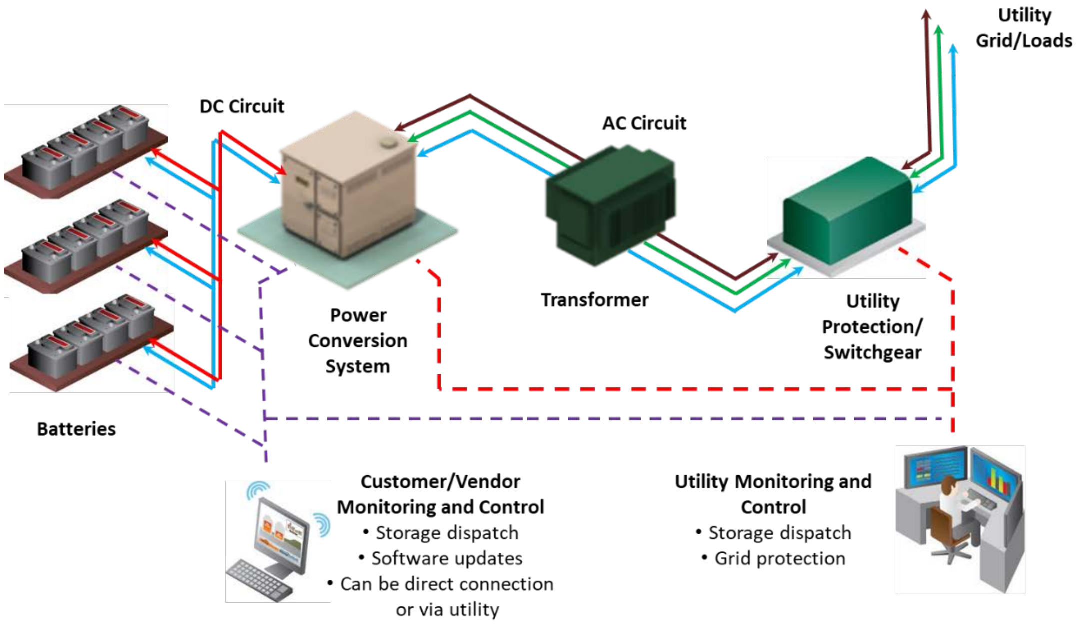

Figure 6. Interrelationships in planning an integrated storage solution

A division of responsibility (DOR) matrix can supplement the SOW and provide additional details and clarity on the interactions among different groups within the project. This is especially important when multiple responsible parties are involved. A DOR matrix template is provided in the EPRI report *ESIC Energy Storage Request for Proposal Guide* [6]. A portion of the DOR matrix template is shown in Table 3.

Table 3. Excerpt of division of responsibility matrix template

Item	Task Description	Design Criteria (Prelim Design)	Detailed Design	Purchase Specification	Procure or Supply	Installation	Testing/ Commissioning
	ESS Equipment						
	Battery (cells, trays, racks, containers, other)						
	Battery (or storage medium) management system (BMS)						
	Power conversion system (PCS), including inverter(s), controls, external communications						
	ESS control system (interfaces, controllers, communications, others)						
	ESS mechanical and structural commodities						
	ESS raceway, wire, commodities						
	ESS shipping/transportation						
	ESS rigging and offloading						
	ESS spare parts						
	Balance-of-plant spare parts						
	Preparation/Structural Work (Site/Building)						
	Foundation or building (new or modifications)						
	Excavation and grading						
	Site access road						
	Fencing						
	Finishing (gravel)						
	Site restoration						

Technical Specifications

The solution requirements determined during the planning stage should be translated into a set of technical specifications in the RFP, which can be either extremely detailed or quite broad to suit the project's needs. The level of detail desired from the technical specification is also affected by the utility's experience level with energy storage integration.

EPRI's *ESIC Energy Storage Technical Specification Template, Version 3.0* [7] can facilitate the communication of technical information between the utility and potential bidders. The template can serve as a starting point to define a list of desired specifications from the suppliers for several categories. General considerations for energy storage projects are described in Table 4.

Table 4. Considerations for technical specifications

Categories	Key Parameters and Considerations
Facility and ESS Performance	Setting minimum requirements and general target parameters for the project will ensure more effective responses to the project solution needs. This is especially critical from a financial and reliability perspective. Conversely, over-specifying performance requirements can overly restrict respondents from proposing innovative solutions. Striking a balance and clearly distinguishing "needs" from "wants" is helpful for the supplier community to optimize system design and make viable offers. One critical parameter to clearly communicate is energy capacity requirements. The requirement should state energy needs throughout the life of the project, if requesting design to beginning of life (BOL) or end of life (EOL) where energy is being measured, and if there are any limitations on the usable state of charge range. It is essential to use consistent terminology, particularly when referring to "nominal" versus "nameplate" versus "rated" energy capacity. Clear communication of these terms helps avoid confusion and ensures all stakeholders have a shared understanding of system capabilities.
Installation	Installation specifications should address project site, size, and other characteristics. Physical protection schemes and devices that will be integrated with the installation must be considered, such as transportation, containment, physical security, and clearances. The structural and civil engineering characteristics of the site may require thorough analysis to understand the extent of site development needed to accommodate the storage system.
Interconnection	Interface requirements are to connect either to a utility-specified transformer or to the voltage level at the chosen site. The interconnection protection scheme and devices that will be integrated with the installation must be considered. The capacity or power quality-related constraints should be considered.
Balance of System	Auxiliary load requirements for the energy storage technology should be stated, including pumps, heaters, chillers, fans, or controls. The power source—whether fed directly from the ESS, from a dedicated power source, or a

Categories	Key Parameters and Considerations
	combination of the two—should be considered. These loads can affect overall facility efficiency and power output.
Controls, Communication, and Cyber Security	Communication, controls, and cybersecurity requirements are increasingly important in the integrated grid. Each project may have different requirements, such as limitations on remote monitoring, simultaneous control functions, encryption, and so on. EPRI published a *Summary of Energy Storage Controls Performance Metrics* to benchmark and compare controller performance in providing different grid services [11]. ESIC has also facilitated industry input on data requirements that support performance, reliability, and safety assessments throughout the life of the project [12].
Mechanical and Environmental	Ambient conditions of the project site, weather-affected load conditions of the system, and sound emissions of the system should be communicated to ensure the proposed system meets the project requirements. Suppliers should provide adequate safeguards against freezing weather to protect the system from related problems, ensuring reliable and uninterrupted operation even in harsh weather conditions.
Safety	Safety measures required to meet project needs should be illustrated clearly, along with identification of expected AHJs, which could include a list of 1) applicable codes, standards, and regulations, 2) safety documentation, 3) fire protection requirements, 4) hazard protection requirements, and 5) contractor safety requirements. Suppliers may take different approaches to safety design at the technology, product, system, or process level. The safety approach should be communicated to ensure it meets owners' and local jurisdictional requirements.
Operations and Maintenance	Operational characteristics, such as startup and shutdown time, should be defined to determine whether the ESS satisfies the criteria for intended use. Planned maintenance requirements should be taken into account as well as estimates of the potential impact of unplanned maintenance.

Review of Energy Storage Proposals

Due to the diversity of the energy storage asset class, energy storage proposals may include a broad spectrum of technologies, configurations, and potentially even supplemental value streams in addition to the core solution being sought by the utility. This is in part a function of the range of solutions requested by the utility. Therefore, the utility should have methods and tools to compare and assess the diversity of different project options to arrive at a uniform, “apples to apples” comparison of the proposals. For example, one proposed system may have a higher upfront capital cost but lower O&M cost over the life of the system.

There may be other business considerations for an electric utility to make decisions regarding procurement, such as prior deployment experience, financial stability, field response capability, and other risk management considerations.

Additional Project Technical and Economic Considerations

After the initial short-listing of top candidates or the final choice of a proposed energy storage project is made by the electric utility, there may be internal or external due diligence that occurs to help ensure that a project meets all requirements and is expected to be cost effective. This may include connecting with various internal stakeholders identified early in the planning process to ensure that all requirements are met by a specific offering. Any exceptions to the specifications by proposers should be carefully noted, examined, and clarified if needed prior to contracting of an energy storage project. The final purchase agreement should reflect all exceptions, if allowable, and have clear stage gates, performance metrics, and contract terms to penalize nonconformance to schedules in order to ensure that the project schedule and budget is realized without delays or overruns.

Selection of the storage system vendor and identification of SOW for both parties should, at this point, allow firm definition of the project budget. It is important for utilities to closely review internal labor costs since significant effort will be needed from numerous parties to support design and installation efforts. Numerous departments will potentially be engaged and affect the budget, and all aspects of integration need to be assessed from a labor and equipment cost perspective. These departments could include metering, protection, distribution planning, IT and OT, communication and control, distribution operations, distribution engineering, network operations, environmental compliance, regulatory compliance, and overall project management.

Procurement Lessons Learned

Included here are lessons learned that were gathered in the course of EPRI projects, conferences, publicly available case studies, and submitted through an ESIC survey (Table 5). Inclusion in this report does not signify a recommendation from EPRI.

Table 5. Procurement lessons learned

Category	Challenge and Impact	Lessons Learned
Budget / Specifications	A supplier expressed their challenge with responding to RFPs. Bids could focus on prioritizing the lowest capital cost or on other criteria that would make the bid most competitive. Without understanding the buyer's priorities, it is difficult to accurately price and provide relevant bids.	Buyers should communicate key priorities and evaluation criteria in the RFP.
Specifications	The initial outline of leading details for projects lacked sufficient detail, particularly regarding the prevention of arc flash incidents.	Investing time in the planning and design phases should include dedicating time to create a sufficiently detailed outline of leading details. This ensures comprehensive coverage of essential safety measures, such

Category	Challenge and Impact	Lessons Learned
		as arc flash prevention, and enhances overall project safety and effectiveness.
Contracting / Specifications	There are still risks associated with energy storage products and suppliers. When the asset is participating in the market, the risks can lead to unexpected project costs and financial impact.	Establish performance assurance using measurable, discrete metrics such as capacity and controllability/function, and avoid relying on vague targets such as market participation to help better define and bound the required product risk.
Contracting	When asking for a budgetary price, some vendors may or may not include the efforts necessary for a turnkey system. This can lead to confusion when comparing prices across vendors and in project planning and cost expectations.	Define full scope and have vendors confirm what they include in their pricing. Use DOR matrix as a tool to differentiate offerings.
Codes and Standards/Safety	Deployments of utility-tied ESSs depended on the safety specifications provided by battery manufacturers, which lacked redundant protection for the BMS.	Utilities should specify safety and include redundant protection to critical control systems such as the BMS.
Warranty/Control	Battery original equipment manufacturers (OEMs) require access to local controllers/BMS for operating history via the internet and have set stringent conditions to maintain long-term warranty coverage. These constraints, while intended to prevent owner abuse, are restrictive and difficult to negotiate.	Avoid rushing the procurement of batteries. Take the time to ensure that the OEM's requirements align with the owner's expectations. This negotiation is complex and requires careful management to balance warranty coverage with operational needs.

Procurement Resources

ESIC, EPRI, and other industry organizations provide a range of resources to assist in the energy storage procurement process. Table 6 highlights the key applications for each resource.

Table 6. Useful resources for energy storage procurement

Resource	Application in Procurement
ESIC Energy Storage Request for Proposal Guide [6]	Use elements of the RFP template to support creation of a SOW.
ESIC Energy Storage Technical Specification Template, Version 3.0 [7]	Buyers can communicate minimum or preferred technical and project requirements, and sellers can communicate proposed system specifications.
DOR Matrix Template (provided in Appendix C of *ESIC Energy Storage Request for Proposal Guide*) [6]	Supplemental SOW clarifies interactions and responsibilities between multiple parties with overlapping roles within a project.
Common Functions for Smart Inverters: 4th Edition [5]	List inverter functional requirements based on use case.
Summary of Energy Storage Controls Performance Metrics [11]	Provides metrics, definitions, and calculation methods to evaluate controller performance to support comparison of controller offerings.
Electrical Energy Storage Data Submission Guidelines, Version 2 [12]	This guideline includes a list of data points and alarms for monitoring and can be used to communicate with bidders to ensure they can provide the level of data required.
Electrical Energy Storage Data Submission Guidelines, Version 3 [37]	This guideline is intended to inform numerous stakeholders on the data needed for given functions, how to prescribe access to those data and the considerations impacting data architecture design, and how to provide stakeholders with insight into the data and data systems necessary to ensure storage can meet growing expectations in a safe, cost-efficient manner.
Energy Storage Integration Council (ESIC) Energy Storage Reference Fire Hazard Mitigation Analysis [13]	The reference hazard mitigation analysis (HMA) helps to support evaluation of various safety approaches. It includes barriers to mitigate hazard threats and consequences.
MESA-DEVICE, Modular Energy System Architecture (MESA) Standards Alliance [14]	MESA-DEVICE specifications address communication of components, including inverters, meters, and the storage medium.
ESIC Energy Storage Commissioning Guide [15]	Includes commissioning-related considerations during the procurement phase.
DOE OE Energy Storage Systems Safety Roadmap [16]	Sandia National Laboratory and Pacific Northwest National Laboratory publish a monthly update of codes and standards changes in active development. In developing an RFP, it is important to understand the latest codes and standards to assess project requirements and potential cost and schedule implications of requiring certain codes and standards.

Resource	Application in Procurement
Safety Implications of Lithium Ion Chemistries [38]	Safety of lithium ion batteries, specifically mitigation of thermal runaway, is a narrowing but persistent gap that has been difficult to fully address alongside rapid technology development and adoption. Safety from the likelihood and consequences of thermal runaway is inherently linked to the chemistry of the materials used within the battery.
The Evolution of Battery Energy Storage Safety Codes and Standards [39]	This report describes the history of the development of safety codes and standards for grid-connected or utility-scale battery energy storage systems (BESSs) in North America as well as how the evolving requirements have influenced stationary BESS installations.
Residential Energy Storage System Safety Guidelines [40]	Residential ESSs using lithium ion batteries can present safety challenges for homeowners and firefighters. While the failure of residential ESS lithium ion batteries is a rare event, fire and explosion hazards have already occurred. This guide provides steps homeowners and ESS installers can take to minimize these hazards.

4 DEPLOYMENT AND INTEGRATION OF ENERGY STORAGE

Introduction to Deployment and Integration

The deployment and integration phase of an energy storage project occurs after the procurement contracting of energy storage has taken place and work begins toward the integration of the project. This phase ends when a project has been installed and commissioned, with the subsequent handoff to operations.

Picking up from the procurement phase, it is assumed at this point that the SOW has been defined for the parties developing the energy storage project. However, experience has shown that this is not always the case. Sometimes the complete scope of energy storage project deployment and integration is not fully considered in advance; in other cases, some steps of the process have been underestimated. Incomplete specifications may result in project delays due to a lack of upfront involvement with all the utility groups with a stake in the ESS and its integration with the power system.

The subsections below review the steps associated with the deployment and integration of energy storage projects, as follows:

- Site and system engineering
- Permitting and applicable codes and standards
- Site preparation and construction
- Factory acceptance testing
- Product shipping and receiving
- Product installation, connection, and integration
- Project commissioning
- Interconnection
- Site acceptance testing
- Safety considerations
- External stakeholder engagement and training

Engineering

The contract executed during procurement should have included the utility and industry design standards and codes that the facility must meet. These, along with the other technical specifications, will be used as the basis of design during the engineering process. In this subsection, engineering is separated into site engineering and system engineering. For both engineering categories, detailed plans for the project may be reviewed by multiple stakeholders, including outside permitting agencies and utility teams responsible for protection engineering, distribution planning, standards engineering, supervisory control and data acquisition (SCADA)engineering, environmental health and safety (EH&S), and IT. Design reviews throughout the engineering process ensure that the supplier and utility are aligned, helping to avoid delays associated with design changes.

Site Engineering

Before project site construction can begin, the energy storage project site must be engineered and specified to accommodate the procured energy storage product. Site requirements may vary by location type (e.g., urban, rural, substation, or customer industrial site). General considerations for site engineering include, but are not limited to, the following:

- Geotechnical analysis to determine soil type and compaction requirements
- Equipment access during construction and project operations (such as cranes, maintenance trucks, and temporary storage)
- Operational and maintenance access
- Work clearances and ergonomic considerations
- Fire barriers
- Explosion and blast analysis
- Water needs for fire suppression
- Noise barriers
- Containment
- Egress
- Flood zones
- Seismic zones
- Physical security and access (such as fencing, key or card reader access, and security cameras)
- Control building or enclosure
- Building design or containerized system
- Equipment foundations
- Buildout for future capacity

System Engineering

Aside from the physical site engineering, the electrical and communication interface between the ESS and the utility system must be considered and addressed. System engineering considerations include, but are not limited to, the following:

- **ESS design:** The ESS may be a packaged system with the vendor providing an integrated product up to the alternating current output of the PCS, or the system may be designed by the supplier using components from several different manufacturers. If the latter, there will be additional engineering required to ensure that all the devices are properly interfaced, and coordination and design reviews with all parties will be critical during the engineering phase. Several key design features in the storage balance-of-plant that may impact performance, reliability, and safety include thermal management, uninterruptible power supply, gas sensing, fire protection and suppression, and BMS integration.

- **Safety system design:** The design of safety systems for energy storage is evolving with industry experiences and lessons learned from incidents. Some features may be integrated into the product, and some may require system-level design. Examples of system-level design include fire alarm control panels, visible and audible alarms, and external water piping systems.
- **Communication, control, and cybersecurity:** This is a critical component of a successfully operating facility and, therefore, it is important to have well-defined requirements, specifications, and DOR in early phases. There are typically two different levels of communication and control—one within the ESS envelope and the other between the ESS and utility interface. Because storage is not as widely deployed as other generation or distribution assets, there may be significant work on integration into the utility infrastructure, such as programming new interface screens and navigating through network and security requirements. Previous projects have shown that integrating storage systems into legacy SCADA systems presents specific challenges that require thorough investigation. It is also important to include provisions for vendors to access their equipment and data log files for diagnostics and troubleshooting. This can be challenging due to cybersecurity requirements; therefore, project planners should involve internal stakeholders related to cybersecurity early in the project planning process.
- **Metering and monitoring requirements:** This may include requirements from the utility, independent system operator (if applicable), and equipment manufacturers.
- **Transformers:** Configuration of any step-up or isolation transformers must match the voltage level at the point of connection and the wiring configuration (such as wye or delta) of the grid.
- **Grounding requirements:** ESS equipment grounding recommendations from various manufacturers may differ from utility standards. Grounding design may also impact the transformer configuration.
- **Protective devices:** In general, there are a number of protection issues to consider for energy storage and DER. Protection issues primarily concern issues of safety and reliability of the distribution system under fault conditions, but they also may concern the protection of the ESS itself. Protection includes the functionality of the PCS (such as response to abnormal voltage and frequency) as well as the configuration and settings of utility system protection (such as circuit breaker, fuse, relay, and recloser) and potential impacts to utility protection schemes. Protection considerations will be different depending on the specific use cases intended for a given ESS installation. For example, in some cases, the utility may want the ESS to shut down in the presence of abnormal conditions, which may be easily accomplished with the storage PCS functionality, recloser, or an external breaker. In other cases, the ESS may be expected to support the electric power system in the presence of

some abnormal conditions and not others, which can add more value to the ESS asset but may also complicate implementation.

- **Power feed for auxiliary loads:** These circuits should be configured to address the effects of upstream protection gear and be designed so that any circuit isolation associated with the storage system does not shut off power to the auxiliary systems.

Permitting and Applicable Codes and Standards

In parallel to detailed site engineering and drawings by internal utility stakeholders, the utility or integrator may need to engage local AHJs for any required permits to construct and operate the energy storage project. Some permitting actions may start with incomplete engineering documents due to the long potential time frame that a permitting action can require. AHJs may include local zoning boards, local fire marshal, and other local planning authorities (county or municipal). In other cases, the utility itself may be the primary or sole AHJ for the project. Even if self-permitting, it is good to engage with the local emergency responders so that they are informed of the project and know how to respond.

Within the last few years, codes and standards have been developed to address the installation of advanced energy storage technologies, such as National Fire Protection Association (NFPA) 855 Standard for the Installation of Stationary Energy Storage Systems and International Fire Code® (IFC®). These standards—with their additional energy storage requirements over previous fire codes including equipment certification, large-scale fire testing, and documentation—have the potential to increase the cost or schedule of a project. However, there may be a delay between the publication of the standards and adoption by AHJs. Therefore, providing training and discussing concerns and requirements for safety, nuisance, or environmental issues with the relevant AHJ much earlier in the process may help to reduce project schedule delays. Safety issues, as they pertain to the permitting process, are being considered within ESIC and through the U.S. Department of Energy (DOE), Sandia National Laboratories, and Pacific Northwest National Laboratories [12].

Awareness of these new energy storage codes and standards and their adoption by local AHJs may become critical for mitigating risk of permitting schedule and costs. In addition to a local AHJ, projects may be subject to additional standards imposed by insurance providers. The Factory Mutual Insurance Company (FM) Global Safety Data Sheet 5-33 is an example of an insurer’s design guidelines [17].

Site Preparation and Construction

When the site engineering and permitting process is completed, site preparation may begin. This work is often performed by a local construction firm, which may or may not be part of a general contractor or engineering, procurement, and construction (EPC) firm that was involved in the design and permitting stages. Site preparation and construction safety hazards, along with other concerns, are likely related to location or environmental conditions.

Factory Acceptance Testing

While the previous steps of site preparation and utility-side considerations are underway, equipment vendors are manufacturing and preparing the ESS product. It is likely that vendors will also be closely engaged with those previous steps to support the utility in addressing ESS-specific questions of internal and external stakeholders.

When the energy storage product manufacturing process is complete, it is a common practice for the utility or a third party to witness a factory acceptance test (FAT) at the vendor's manufacturing facility or integrator's facility prior to shipment. The FAT is typically a set of quality control-related tests to help ensure that the components of the ESS have been built to specification prior to its leaving the factory. A FAT may be a semi-standardized process, but it will likely be augmented for specific considerations of a manufacturer, product, utility, and project. If separate manufacturers are supplying the components, a FAT of the assembled system may be impractical or add cost to assemble and then disassemble for shipping. FATs are primarily used as a risk management stage gate for the project and can help to reduce the field testing and commissioning schedule. It may be important to use the FAT to ensure proper communication integration among various suppliers' control systems if separate vendor control systems are being integrated at the site.

Product Shipping and Receiving

After the ESS is approved for shipment, it is transported to the utility site. There are a number of considerations in this process, including practices for loading and unloading equipment, modes of transportation, weight, dimension limits for containers, and existence of regulations associated with shipping ESSs (including hazardous materials, as applicable by technology). Clear terms for equipment delivery and logistics are important considerations because they can have cost implications. Occasionally, the equipment delivery might not coincide with the exact start of equipment installation, and temporary storage fees may be incurred. Responsibility should be assigned for costs such as warehouse storage fees, material handling equipment rental fees, storage container rental fees, and labor fees. Also, the chain of custody of the equipment must be carefully considered to ensure that responsibility and insurance aspects are covered.

For loading and unloading, as generally for shipping, it is important to consider any weight or dimension limits for any mode of transportation used as well as the availability of cranes or forklifts as needed at the project site. In addition, the project site must be able to accommodate any required lifting equipment and delivery vehicle ingress and egress.

Regulations for safety of items being shipped are managed by several authorities, including the U.S. Department of Transportation for shipments by road, potentially Homeland Security and International Maritime Dangerous Goods Code authorities for shipments by sea, and International Air Transport Association for shipments by air. For hazardous materials, a set of tests has been developed through the United Nations; these tests, for example, are a consideration for regulating shipment of lithium-based batteries [18]. Similar tests may be applicable for other energy storage technologies that are energized during transport.

Provisions for temporary storage also must be factored in if equipment deliveries are not perfectly sequenced with subsequent installation tasks.

Product Installation and System Integration

ESS product installation and system integration can be performed by a local electrical contractor, which, like the site preparation and construction, may be part of a larger general contractor or EPC organization. The electrical contractors should be experienced in both high- and low-voltage systems and be familiar with the local electric utility's system, but some may be unfamiliar with energy storage technology. As a result, sufficient training and documentation is important to ensure that the contractor knows about safety hazards and procedures unique to ESSs. Codes, standards, and regulatory publications as well as vendor-specific operation manuals are good resources for contractors to familiarize themselves with ESS product installation and system integration.

ESS product installation processes may vary widely depending on the size, configuration, and technology used. In some cases, components will be shipped separately, resulting in extensive on-site assembly by the manufacturer or integrator. Alternatively, a smaller, pre-engineered, modular product could be fully or almost fully assembled and ready to be wired.

Project Commissioning

Following installation and connection of an ESS to the utility grid, a commissioning phase is required to ensure successful integration. Commissioning is defined by IEEE as "[a] process that assures that a component, subsystem, or system will meet the intent of the designer and the user" [19]. These tests are intended to address the following list of typical concerns:

- Was the system installed correctly and remains within specification?
- Is the utility switchgear and protection equipment operating as designed?
- Are the communication and control systems fully operational?
- Are all safety systems properly installed and operational?

In defining the commissioning effort, it is important to identify the personnel involved and the timing of their involvement. Typical commissioning efforts involve numerous entities and many personnel, and the unavailability of key personnel can derail the commissioning time schedule. The growing number of projects being deployed often means that resources are scheduled back- to-back, and it can be challenging to reschedule commissioning visits. As a result, proactive planning and communication are critical to ensuring that resources are available.

Timing for configuring, testing, and verifying utility metering and communications should also be factored in carefully. In addition, permission from the local grid to charge and discharge the system must also be planned into the timing. This permission can sometimes cause delays and result in project teams unexpectedly remaining mobilized on site.

ESIC commissioning guidelines detail commissioning during the deployment and integration phase. The guidelines also address commissioning considerations throughout the project life cycle, such as schedule, cost, and responsibility [15].

Figure 7 illustrates a typical timeline from construction and installation through site acceptance testing.

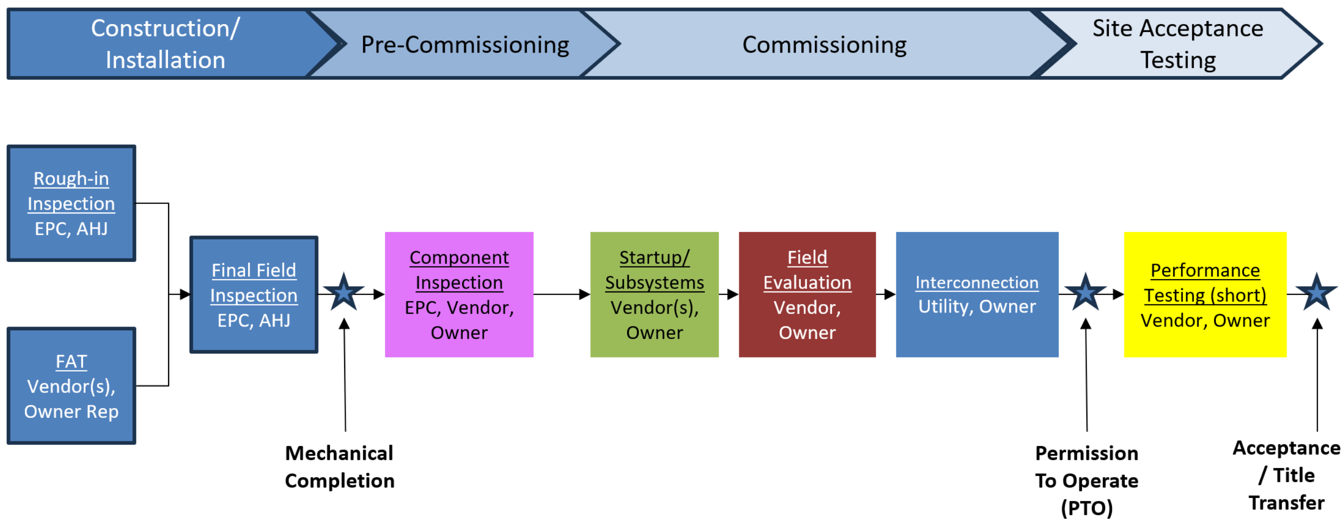

Figure 7. Construction and commissioning flow chart

Interconnection

Commissioning ensures that the ESS meets operational and performance specifications. Before the system is allowed to interconnect with the grid, tests and documentation may be required to ensure compliance with interconnection standards and the overall contracted specifications. The interconnection standards may include IEEE 1547.1a, IEEE 1547.1, or other utility-specific requirements. EPRI's *ESIC Energy Storage Commissioning Guide* [15] further details inverter functionality requirements in IEEE 1547 as they relate to interconnection.

Site Acceptance Testing

In addition to ensuring the proper integration of the ESS into the utility system through commissioning, performance and functional tests may be required to verify that the system operates as specified. Any tests required for acceptance and associated penalties for noncompliance should be established during the procurement phase so that the buyer and seller's expectations are aligned. This includes defining how the tests will be performed. The EPRI report *Energy Storage Integration Council (ESIC) Energy Storage Test Manual* has a full outline of potential functional and performance tests that a utility may request to perform as well as a comprehensive set of detailed test protocols that include a measurement and calculation method, testing duty cycles, and templates for data collection [4]. This manual is periodically updated through ESIC based on industry feedback, and new test protocols are added.

Safety Considerations

There are unique safety considerations during the deployment and integration phase of the project because not all safety systems may be in place or fully functional during the shipping, construction, and commissioning phases. This has been highlighted as a result of several battery fire incidents in 2021 that occurred prior to system commissioning [20]. A separate HMA for this phase of the project would help in identifying risks and inform mitigation approaches [13].

External Stakeholder Engagement and Training

Various stakeholders should be engaged throughout this phase of the project. This may include first responders, O&M personnel. Depending on the size, location, and other project details, it may be valuable to engage first responders, such as the local fire department, earlier in the process to ensure they have a good understanding of the system hazards and are comfortable developing a response plan. Training is typically provided before the project closeout.

Deployment and Integration Lessons Learned

Included here are lessons learned that were gathered in the course of EPRI projects, conferences, publicly available case studies, and submitted through an ESIC survey (Table 7). Inclusion in this report does not signify a recommendation from EPRI.

Table 7. Deployment and integration lessons learned

Category	Challenge and Impact	Lessons Learned
Communications / IT	Inability to provide remote access due to security concerns, combined with slow project planning from IT, led to delays. Setting up the virtual private network (VPN) took longer than expected due to coordination issues between the storage vendor's IT and the utility's IT groups, including challenges with firewall changes and token sharing.	Discuss and clarify IT requirements early in the project to avoid delays. Consider potential solutions such as isolating the system on a standalone network or using firewall configurations to address security concerns.
Communication	There can be challenges in deploying ESSs using proprietary communication methods, which complicates integration into utility controls.	Use standardized communication protocols to simplify the integration of multiple ESS deployments into utility controls. Validate Modbus maps and firmware in a controlled environment prior to commissioning.
Safety / Thermal Management	Some suppliers fail to design systems with adequate safeguards against freezing weather, such as heat tracing or fail-safe/deenergize mechanisms, leading to burst pipes, equipment damage, or delayed startups due to frozen outlet points.	Ensure any system that may generate condensation or has water loops is fully fail-safe in freezing weather. Implement heat tracing, fail-safe/deenergize designs, and adequate thermal insulation to prevent freezing-related issues and ensure reliable system operation.
Safety	A busbar was not sitting flush on a battery module terminal, potentially due to a manufacturing issue or shipping damage. The terminal bolt was torqued correctly, hiding the issue during visual inspection. During additional acceptance testing, smoke was detected due to arcing between the module and busbar, resulting in melted insulation. This necessitated replacing the entire battery rack.	Ensure installers verify flush busbar contact with terminals before installing bolts. Recognize that testing alone may not identify poor connections, as issues such as arcing can develop weeks into operational testing.
Safety	High-voltage busbar discharge through vented cell gases caused substantial localized metal damage.	Model cell venting scenarios to understand the impact of vented gases on the environment. Improve high-voltage busbar protection to prevent discharges through vent gases.

Category	Challenge and Impact	Lessons Learned
Performance	A system was deployed with three separate meters, but the site controller logic only utilized two of them (battery and building meters). This setup required adding a connection to the third meter to verify battery dispatch, and the metering locations confused the site controller logic.	Seek clarification from the vendor on whether the metering location strategy is appropriate for the system deployment. Ensure that the metering strategy is efficient and well-integrated with the site controller logic.
Control	The site control did not account for the incompatibility of a new data acquisition system with the existing system, leading to significant issues in data acquisition and delivery.	During the proposal review and contract award phase, comprehensively consider the compatibility and integration of the data acquisition and delivery systems to avoid operational failures.
Specifications	During commissioning, it was discovered that the supplier had shipped the power conversion system (PCS) with the wrong firmware. The supplier had chosen a new firmware release for integration but failed to communicate this to the integrator.	Develop better commissioning plans and conduct thorough due diligence on supplier scopes and commissioning expectations to ensure proper communication and avoid such issues.
Codes and Standards	A developer neglected safety considerations and failed to cooperate with local fire safety officials, resulting in numerous safety issues and code violations that posed significant risks to first responders.	Engage meaningfully with code officials, educating them about the systems, and ensure that systems are designed to be safely monitored and responded to by local emergency response teams. Be good stewards for the industry by prioritizing safety and compliance.
Contracting/ Scheduling	A vendor faced issues during the factory acceptance test that took months to resolve due to a lack of understanding of the required use case operations and controls. This delay necessitated additional funds for installation, which had to be sourced unexpectedly.	Be cautious about purchasing first-of-a-kind (FOAK) products. Focus on acquiring proven and reliable energy storage products.

Category	Challenge and Impact	Lessons Learned
Maintenance	Half a year after commissioning, unresolved issues persist with the BESS, including data points reading as zero. The vendor considers these issues non-urgent, causing delays in internal efforts and leaving the data unreliable. The root cause is still unknown, and obtaining adequate support from the vendor remains challenging.	Address minor issues promptly while the project details are still fresh in everyone's mind. Ensure the vendor commits to resolving all issues, no matter how minor they seem, to maintain reliable system performance and support internal operations effectively.

Deployment and Integration Resources

EPRI, ESIC, and others provide resources for energy storage deployment and integration, as shown in Table 8.

Table 8. Useful resources for energy storage deployment and integration

Resource	Application in Deployment and Integration
Insights from EPRI's Battery Energy Storage Systems (BESS) Failure Incident Database: Analysis of Failure Root Cause, 3002030360	This report emphasizes the importance of proper integration and controls.
ESIC Energy Storage Technical Specification Template, Version 3.0 [7]	Information collected during procurement can be used to support site engineering, interconnection and protection studies, and the permitting process.
Battery Energy Storage Systems Explosion Hazards [21]	Provides insight into explosion hazards that need to be considered in site design.
NFPA 855 Standard for the Installation of Stationary Energy Storage Systems [22]	Standard may be adopted by local AHJs.
IFC® 2021, Chapter 12 Energy Systems [23]	Standard may be adopted by local AHJs.
Energy Storage System Permitting and Interconnection Process Guide for New York City Lithium-Ion Outdoor Systems [24]	Example of one city's approach to integrating storage into the permitting process.
Energy Storage Integration Council (ESIC) Energy Storage Test Manual [4]	Follow test protocols during commissioning or acceptance testing to verify system performance and functionality.
ESIC Energy Storage Safety: 2016, Guidelines Developed by the Energy Storage Integration Council for Distribution-Connected Systems [41]	Understand safety considerations during this project phase.
ESIC Energy Storage Commissioning Guide [15]	List of tests and design and construction verification activities; links to examples of commissioning procedures.

Resource	Application in Deployment and Integration
FM Global Property Loss Prevention Data Sheets, 5-33: Electrical Energy Storage Systems [17]	Example of an insurance provider's design guidelines.
Proactive First Responder Engagement for Battery Owners and Operators [25]	Includes a range of practical actions, discussion topics, and resources that could be undertaken or used to create improved safety conditions for workers or first responders to reduce information barriers, streamline permitting, reduce project delays and costs, inform corporate risk discussions, and build confidence and trust with stakeholders.

5 PROJECT OPERATIONS AND MAINTENANCE

Introduction to Operations and Maintenance

The O&M phase of an energy storage project begins when the system has been commissioned and approved for use in an electric utility. This phase continues until the end of the project's operational life, which could be 10–20 years after installation or even longer. This should be the longest phase of an energy storage project implementation; therefore, proper planning and budgeting in earlier project phases helps to ensure the system can continue to safely and reliably perform its objectives throughout its intended life. Such issues are becoming increasingly critical as ESSs grow in size and the grid becomes more dependent on these assets for reliability functions.

Although O&M are often bundled together because they occur in the same project phase, the stakeholders engaged in those activities often differ. Operations personnel are responsible for ESS dispatch, while maintenance groups are responsible for the upkeep of the storage system. In parallel, asset managers are responsible for long-term planning and health decisions for the system and fleet, including coordination and scheduling of replacements or capacity augmentations, system health and degradation monitoring, availability assessments, performance assessments, and warranty management.

The optimal balance between efficient operations cost and high reliability is a focus of emerging research at EPRI and other entities through analysis of field performance and maintenance actions. These new efforts ultimately aim to define operational best practices by analyzing experienced operational parameters and development of assessment tools.

The following steps are associated with project O&M:

- Handoff to system operations
- ESS maintenance
- Environmental and safety reporting
- Update operational needs (as required)
- Recommissioning (as required)

System Operations

At the start of ESS project operations, it is important that system operators (and other parties with control of storage system) are well informed and trained regarding the storage system operational software, intended use of the project, protection systems and schemes employed, and planned operational profile of the storage system. Operational coordination will vary depending on the existing utility communications and control infrastructure (such as whether a DERMS is being used) and the size and level of aggregation of energy storage deployment. Operators should understand the differences between energy storage and conventional utility assets. For instance, energy storage is limited by timing interdependencies, meaning that before energy can be dispatched from storage, a corresponding quantity of energy must have been stored from a charging period.

The storage safety plan must be solidified as well, with clear knowledge of where alarms are sent and attended to and ensuing emergency response plans based on various levels of alarms and the first responders who would be aligned to the system.

Maintenance

Maintenance of any asset comes in two forms: preventive and corrective. Preventive maintenance may be scheduled relative to time (e.g., quarterly, semiannually, or annually) and level of usage (e.g., after a number of cycles), or it may be triggered based on monitoring or performance data and other factors such as environmental conditions. Depending on the configuration and technology used in an energy storage project, regular diagnostic checks may be able to identify issues with ESS degradation or underperformance and enable a technician to strategically replace components rather than an entire system.

Corrective maintenance is typically costlier, because it may require unanticipated service calls or prolonged loss of service. In addition, if unplanned maintenance events occur when the storage system is expected to perform a service and is unavailable, this could result in power system reliability issues and/or financial penalties to the entity responsible for successful energy storage operation. Unplanned maintenance is a consideration for design of warranties and service contracts. Many instances of unplanned maintenance should be avoidable through planned maintenance and diagnostics on system state of health (SOH).

Leading maintenance practices continue to evolve as the industry gains more operational experiences that inform both maintenance activities and design of future systems. To support the development of these practices, ESIC published the *Energy Storage Operations and Maintenance Tracker* to support uniform data collection and enable operational analytic assessments [26]. Experiences to date have identified several items with potential to impact system availability and functionality.

- **Firmware updates:** These updates need to be properly coordinated between the various device levels (e.g., BMS, inverter, and emergency management system) to ensure data and communication mapping and system-level functionality remain in place. This may include having a plan with firmware upgrade reviews (e.g., functional and cyber security), procedures (e.g., remote or site access), and testing in place prior to operations handoff.
- **Spare parts:** Provisioning of spare parts that require more frequent replacement (such as air filters) should be considered as part of the initial product delivery. The spare parts inventory, replenishment plans, and storage location(s) must be actively managed.
- **SOH tracking:** SOH calculations vary between vendors, and lack of visibility may impact O&M decision making. Therefore, the responsibility for tracking and method for determining system SOH should be established during the procurement process. This includes identifying what data points will be needed, how the data will be collected and transmitted, who will monitor the data status, and what triggers maintenance or further

investigation. Mandated response times could be manifested in warranty and service agreements to enforce rapid response to unplanned maintenance. For utility-owned systems, there are various approaches to the DOR of maintenance tasks. Maintenance services agreements can be set up to contract all or a portion of the maintenance to the EPC personnel, integrator, technology supplier, or third party. With proper training and program development, maintenance can also be performed in-house. When determining a maintenance strategy, the warranty or any other guarantees should be considered because there may be additional maintenance requirements (e.g., use of certified workers and frequency of tasks) to uphold those contracts.

Major Replacements and Augmentation

Depending on the duration of the project life, there may be a need to replace or augment major system components such as battery modules, PCSs, or other balance-of-plant equipment. If maintenance takes the system offline for some time, it should be scheduled to minimize impact to the grid and the services that the storage is providing. In addition, if maintenance includes the replacement of major system components, the system should be recommissioned to verify proper operation.

For many battery technologies, such as lithium ion and lead acid, the energy capacity will degrade over time due to cycling (charging and discharging) and calendar life. There are several ways to address this degradation, including the following.

- **Oversizing:** While installing additional energy capacity at the start of the project will have higher upfront capital costs, such a time frame may be preferred if a utility is trying to capture the U.S. federal investment tax credit for solar PV. The disadvantage is that such oversizing forgoes the advantages of potential future cost reductions, performance enhancements, or safety improvements.
- **Augmentation:** This involves installing additional modules during the project's operational life. Augmentation requires expandable system design including structural and electronic components. Augmentation provides flexibility to owners as needs may change over time. Strategies such as when to augment and how to integrate with the existing system are continuing to evolve as the industry gains more experience.
- **Replacement:** This involves installing new modules to replace the original modules. Compared to augmentation, replacement may require more modules to be installed because the modules removed may still have useful remaining life that augmentation could have taken advantage of.
- **Degradation tolerance:** Depending on the use case, it may make sense to allow the system to degrade, rather than try to maintain a certain energy capacity.

Performance Testing and Guarantees

Additional performance testing may be required if performance guarantees were contracted or for utility modeling purposes. Performance guarantees can be put in place to ensure that the system is performing to specifications as agreed upon. Similar to maintenance, some performance tests may make the system unavailable to perform its grid services and should be scheduled to reduce impact. The *Energy Storage Integration Council (ESIC) Energy Storage Test Manual* includes an operational test procedure that can be used throughout the project life to verify system performance [4].

Environmental, Safety and Reliability Reporting

Depending on the type and size of the storage system used, there may be an ongoing requirement to report chemical content, operational status, and other parameters to AHJs and first responders.

These requirements should be clearly identified in the original permitting process, and steps should be taken so that ongoing responsibilities are institutionalized to ensure that change of personnel does not result in missed reports and subsequent fines. In particular, the EPA's Emergency Planning and Community Right-to-Know Act (EPCRA) requirements [27] should be referred to. The North American Electric Reliability Corporation (NERC) has also developed reliability reporting requirements for ESSs tied to solar generation systems; these requirements came into effect in early 2024 [28].

Update Operational Needs

Because energy storage operational approaches are likely to evolve, it is important to have a flexible view of how the ESS will be used, with consideration given to how it may support other portions of the electric grid beyond the distribution system to which it is connected. This implies that the capability to have firmware updates and extend interoperability with additional control systems may be helpful to maximize the value of the energy storage over its operational life. It should be noted, however, that firmware updates may well trigger retesting of the system protection and integration features and associated conformance to any interconnection agreements.

Modeling and simulation efforts may help provide an understanding of a system's future demand and current operating needs for energy storage projects. Production simulations are increasingly performed with a 5–10-year time frame for the bulk electricity system for the purpose of generation resource adequacy planning and to understand the impacts of higher penetrations of renewables. Power flow models used on the distribution system also help to better predict grid needs and improve operational approaches with existing assets. Efforts are currently underway to advance the state of the art for energy storage operational modeling. The methods and associated modeling tool requirements are being considered by the Grid Services and Analysis focus area.

Changes in operation outside the warranty provision or agreed upon use case may need to be discussed with the vendor or supplier. In addition, depending on the performance and functional testing during commissioning, the changes may require that the system be recommissioned for its new intended purpose.

Recommissioning

Similar to commissioning, recommissioning is performed to confirm that the system is behaving as intended. However, recommissioning is typically triggered by a major change in the system, such as a change in operational need or the replacement of major components or firmware, as described earlier in this section. During procurement or service contracting, it is important to identify when recommissioning is needed, the scope of tests, and responsibilities to ensure that expectations are aligned and cost is properly accounted for. EPRI's *ESIC Energy Storage Commissioning Guide* [15] may be used as a reference for tests and procedures for recommissioning; however, the scope may be more limited than the initial commissioning if only a portion of the system changed.

Operations and Maintenance Lessons Learned

Included here are lessons learned that were gathered in the course of EPRI projects, conferences, publicly available case studies, and submitted through an ESIC survey (Table 9). Inclusion in this report does not signify a recommendation from EPRI.

Table 9. O&M lessons learned

Category	Challenge and Impact	Lessons Learned
Auxiliary Systems – HVAC	Frequent HVAC component failures—including contactor failures, control board failures, and thermostat controller failures—led to significant downtime. Despite requests, the original units were not replaced with more reliable ones. Containers with the same settings exhibited consistent temperature differences, an issue not present in similar systems with different HVAC units from the same vendor.	Be cautious of the auxiliary systems chosen by the vendor. If the vendor uses multiple sub-vendors for components such as HVAC units, suggest selecting those with a proven reliability track record to avoid frequent failures and ensure consistent performance.
Communication/IT	An inverter firmware update reset inverter settings, causing excessive generation on the transmission system.	Include a requirement in contracts that all updates must be tested by the owner or proven before implementation and must have the owner's permission.
Communication/IT	A lack of communication and understanding among vendors and integrators led to unforeseen issues when minor firmware upgrades requested by a vendor for their battery system affected integration with an inverter from another vendor.	Ensure that all vendors and parties involved in the ESS are fully informed about any software or firmware changes. Implement change management protocols or mandate testing prior to allowing firmware upgrades. All parties should understand how these changes

Category	Challenge and Impact	Lessons Learned
		will impact other systems to avoid integration issues.
Communication/IT	A supplier's reliance on cellular access to the site controller has led to several operational issues, including difficulties obtaining known data during system anomalies, data loss due to supplier data purges, and prolonged periods where remote connectivity was lost. This loss of connectivity impacted both the supplier's ability to monitor the system and their service effectiveness, even when personnel were on-site.	Whenever possible, opt for a wired solution for supplier remote access to the system to enhance reliability. Discuss and understand the supplier's data logging and purge policies to ensure data integrity. Additionally, ensure that operational warnings and alarms that typically alert the supplier are also communicated to the operators to maintain situational awareness even during connectivity issues.
Safety	A presumed lightning strike to the point of interconnection resulted in blown internal fuses in all inverters.	Design systems to account for lightning strikes by including external power supplies to provide DC voltage to inverter boards. This precaution is important even for systems not located near large solar or industrial sites to enhance resilience against lightning-related damage.
Safety/System Performance	A server electronic failure, compounded by the lack of redundancy, impaired remote visibility and data collection for the ESS.	Conduct a comprehensive failure analysis for power and communications paths when defining the system. Incorporate redundancy, alternate paths, or systems to address critical "what if" scenarios. Implementing multiple backups of all control software and programming, despite the additional patching and configuration control challenges, can mitigate the impact of server failures and maintain system functionality.
System Performance	Changes to the loads applied to the system due to shift in services can cause severe degradation of battery performance due to the resulting operational demands.	Understand the capabilities and limitations of the battery chemistry being installed, as well as how it performs as an integrated system under various demand scenarios. This knowledge enables the system to adapt to new services without causing damage or degradation.

Operations and Maintenance Resources

EPRI and ESIC provide resources for O&M, as shown in Table 10.

Table 10. Useful resources for energy storage operations and maintenance

Resource	Application in Operations and Maintenance
Lessons Learned from Air Plume Modeling of Battery Energy Storage System Failure Incidents, 3002030586	This work describes considerations and lessons learned in the course of modeling lithium ion battery plumes released during thermal runaway.
Pathways to Improved Energy Storage Reliability, 3002030387	Evaluates indicators for energy storage reliability and describes challenges and opportunities for increased reliability.
Energy Storage Operations and Maintenance Tracker [26]	Use for data collection to enable operational analytic assessments; tool also provides a list and structure for the DOR to clarify the responsibilities of various parties.
Energy Storage Integration Council (ESIC) Energy Storage Test Manual 2021 [4]	Use test protocol for extended performance testing or recommissioning.
DER-VET and StorageVET [2, 3]	Understand cost-benefit and dispatch impacts due to changes such as load forecast, grid services, and market pricing. These products may also help in identifying when to schedule O&M to reduce potential revenue impact.

6 DECOMMISSIONING AND END OF LIFE

Introduction to Decommissioning

The final phase of energy storage project implementation is decommissioning and EOL. This phase occurs at the end of the O&M phase when the project is no longer viable—due to a predetermined project end date, safety concerns, or reliability issues or because the marginal costs of continued operation exceed marginal benefits.

The decommissioning phase could be overlooked early in the project because it is expected to occur many years in the future. However, having a decommissioning plan defined at the beginning of the planning process can help to ensure that a project's EOL is a smooth process. There has been an increase in options for recycling and EOL logistics services to support this process. Some considerations include the following:

- Decommissioning issues during prior project phases
- Definition of EOL
- Alternatives for EOL

Decommissioning Issues During Prior Project Phases

It is important to consider decommissioning at the front end of the project. Following are some specific considerations:

- **Planning**: The costs of decommissioning, as well as expected salvage value, should be considered in the cost-benefit analysis for a project. For a project with a long life and a relatively small decommissioning cost, decommissioning may be immaterial to the upfront planning decisions. However, uncertain costs and reliability could result in an unexpectedly high decommissioning cost and a liability for the utility.
- **Procurement**: Safe and environmentally compliant decommissioning should be considered part of the "scope of supply" for the vendor, utility, or a third party. The ESS could be either an asset or liability at EOL depending on the costs of disposing of certain components and the value of recycling, refurbishment, or reuse of other components. In some cases, there may not be an established recycling or disposal infrastructure for emerging technology solutions, which may factor into decision making.
- **Deployment and integration**: During the deployment and integration phase, consideration of the decommissioning process may inform better system and site engineering that could support improved site flexibility to increase salvage value or decrease the cost of decommissioning (e.g., system design for ease of removal). In addition, the decommissioning plan could be relevant for environmental compliance and permitting.
- **Operations and maintenance**: Similar to operating and maintaining a car, the choices made for operating and maintaining an ESS will impact the timing of EOL conditions as well as the associated costs for the project. Operators should be aware of the costs and benefits of

different choices and be informed of the *likely* costs or benefits associated with decommissioning the project. Front-end permitting may dictate actions on decommissioning that must be memorialized to ensure compliance.

End-of-Life Conditions

At the beginning of a project, an end-of-life condition should be defined for energy storage projects to ensure the safety, reliability, and cost-effectiveness of the project. For energy storage technologies, especially batteries, these conditions may be defined by a threshold for energy storage capacity (in megawatt hours), as a percentage of nameplate, or a round-trip efficiency threshold. However, in practice, the EOL conditions may be defined by a major maintenance event that operators determine is not worth the cost of repair (like a new transmission for an old car) or if there is a perceived safety risk. Close communication between the energy storage supplier and the utility may help to support decision making around this topic. Another option to decommissioning could include re-specifying the project to perform less demanding tasks that are less taxing on the plant and may extend its life with lower maintenance costs.

Decommissioning Plan

When the decision to decommission an ESS is made, a well-defined decommissioning plan can help ensure a safe, efficient process. Section 6 of the EPRI report *ESIC Energy Storage Commissioning Guide* outlines the key steps and considerations in a successful decommissioning plan, including decommissioning scope, risk management assessment, safety plan, environmental assessment, recycling and disposal considerations, pre-shutdown considerations, and post decommissioning activities [15].

ESIC hosted a Battery End-of-Life Case Study webcast in March 2021, which shared lessons learned from the decommissioning of a lithium ion battery system [29]. Critical items and specialty skills required included battery handling, deenergization, and planning of the execution and disposition. Safety planning included a readiness review, personal protective equipment (PPE) requirements, lock-out-tag-out (LOTO) procedures, and a hazardous materials plan.

Material disposition was a combination of reuse, recycling, and disposal. One of the key lessons learned was having all necessary documentation (bill of lading, specification sheets, as-built drawings) to support logistics planning and execution. EPRI's Cedartown BESS Decommissioning Case Study details lessons learned from the decommissioning and recycling of a lithium ion BESS purchased by EPRI through a research project funded by Southern Company [35]. Additional insights from that case study as well as other published EPRI reports are listed in Table 12.

Decommissioning Lessons Learned

Included here are lessons learned that were gathered in the course of EPRI projects, conferences, publicly available case studies, and submitted through an ESIC survey (Table 11). Inclusion in this report does not signify a recommendation from EPRI.

Table 11. Decommissioning lessons learned

Category	Challenge and Impact	Lessons Learned
Schedule	Decommissioning costs exceeded expectations, primarily due to insufficient system information and inadequate planning time.	Allow adequate time for decommissioning planning to gather comprehensive system information and prepare effectively. Chemistry, make, model, and architecture can influence the costs of decommissioning and recycling.
Schedule/Cost	Battery container dimensions were inaccurate, causing difficulties with transportation due to discrepancies between documentation and actual dimensions.	Field-verify the dimensions of equipment prior to removal to ensure compatibility with transport vehicles and avoid complications.
Transportation / Regulatory	During a decommissioning of a lithium ion BESS, proper hazmat shipping requirements for labeling were not followed. A truck carrying the unlabeled and packaged battery modules was intercepted, and correct labeling was applied on the road before continued transport was allowed.	Verify regulatory requirements for safe transport of decommissioned battery modules before trucks leave the site.

Decommissioning Resources

EPRI and ESIC provide resources for decommissioning, as shown in Table 12.

Table 12. Useful resources for energy storage decommissioning

Resource	Application in Decommissioning
ESIC Energy Storage Commissioning Guide [15]	Understand key components of a decommissioning plan.
ESIC Battery End-of-Life Case Study Webcast [29]	Lessons learned from a contractor and recycler for a lithium ion decommissioning project.
Recycling and Disposal of Battery-Based Grid Energy Storage Systems: A Preliminary Investigation [30]	Addresses disposal and recycling of lithium ion battery systems.
Lithium Ion Battery Energy Storage End-of-Life Management Infographic [31]	This infographic summarizes a variety of metrics for EOL management of lithium ion batteries.
Guidelines for Assessing End-of-Life Management Options for Renewable and Battery Energy Storage Technologies [32]	Compilation of best practices and guidelines for decommissioning renewable and battery energy storage facilities
Solar Photovoltaics, Lithium-Ion Battery, and Wind Turbine Blade End-of-Life Service Providers [33]	List of entities within the United States that have stated that they participate in EOL activities. The list is intended as a starting point for those who would like to know about potential options for recycling, reuse, or disposal after decommissioning.
NAATBatt Lithium-Ion Battery Supply Chain Database [34]	Database includes North American companies that support EOL management.
Cedartown Battery Energy Storage System Decommissioning Case Study: Lessons Learned from Decommissioning an Early-Stage Utility-Scale Lithium Ion Project [35]	This report summarizes the preparation, process, and lessons learned from the decommissioning and recycling of a lithium ion BESS purchased by EPRI through a research project funded by Southern Company.

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About EPRI

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

Program:

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