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Energy Storage Financing: *Operations & Market Strategy*

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ABSTRACT

This Study investigates the impact that operations and market strategy have on the design and value of an energy storage system on three levels of the facility: the cell level, the system level, and the project level. The study provides insights for developers, capital providers, customers and policy makers into the impact different operational strategies have on effectiveness of energy storage system in today's emerging market. Energy storage systems can be used for a variety of usage profiles, with the choice having a profound impact on their performance, lifespan, and revenue potential. Most evaluations of application stacking only look at the possible revenue potential without understanding the increased costs and potential for major damage to the cells. Evaluating the impact of operational choices is critical to understanding the risk adjusted return from energy storage project investment. This is the fifth study in the Energy Storage Financing Study series, which is designed to investigate challenges surrounding the financing of energy storage projects in the U.S., promoting greater technology and project risk transparency, reducing project transaction costs, and supporting a level playing field for innovative energy storage technologies.

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- Keynote Janea Scott, California Energy Commission
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EXECUTIVE SUMMARY

This Study investigates the impact that operations and market strategy have on the design and value of an energy storage system on three levels of the facility: the cell level, the system level, and the project level. The study provides insights for developers, capital providers, customers and policy makers into the impact different operational strategies have on effectiveness of energy storage system in today's emerging market. Energy storage systems can be used for a variety of usage profiles, with the choice having a profound impact on their performance, lifespan, and revenue potential. Most evaluations of application stacking only look at the possible revenue potential without understanding the increased costs and potential for major damage to the cells. Evaluating the impact of operational choices is critical to understanding the risk adjusted return from energy storage project investment. This is the fifth study in the Energy Storage Financing Study series, which is designed to investigate challenges surrounding the financing of energy storage projects in the U.S., promoting greater technology and project risk transparency, reducing project transaction costs, and supporting a level playing field for innovative energy storage technologies.

Challenges & Opportunities

Operations and market strategy is the next critical challenge in the stationary energy storage market. Many early successful market roles of energy storage assets were single application power related activities, such as frequency regulation (FTM) and peak shaving (BTM) which relied on availability and responsiveness of the asset, but could manage with shorter discharge durations, and even significant degradation of the cells without impacting the primary use of the asset too severely. Increasingly, successful market roles for energy storage assets incorporate multiple applications, which both can interfere with the unit's availability with each other's dispatch availability and capability, require a number of other performance characteristics, and balance of use of the asset in the short term vs. long term in order to provision the full contractual obligation of the facility.

The opportunities for project developer lie in the ability to understand how these issues are integrated into the design, operation, and project development of energy storage projects. The challenges and opportunities for energy storage project development incorporates aspects at all levels of the system architecture. At the cell level, technical design and performance attributes of the technology will impact usage. At the system level, system integration capabilities dictate the bankability of the resulting system. At the project level, the ability to support and guarantee off-take capabilities directly impacts the revenue certainty of the unit, and how valuable the project is. Through this framework, it can be seen that all aspects of the design and operational choices impact how a project can be developed, and what it can accomplish.

Cell Level

The goal for an energy storage technology is to balance the needs and requirements for charging and discharging energy from the core storage device. There are a number of key attributes surrounding this action, that will impact both the design and cost of the unit, and also the capabilities of any system designed around these core technology systems, including the rate of charging, the total amount of storage capacity, the impact of operation on the physical components of the storage medium, etc. These attributes will define basic design challenges for OEMs, but also present some opportunities when comparing different technologies supporting the same application.

System Level

The goal for an energy storage system is to balance to need to incorporate the most capability into the system at the lowest costs. This goes beyond simple energy rating (kWh) and power rating (kW) as the value in the system is based on one that can be used (a) more often, (b) more dynamically, and (c) safer. Since there are a number of possible applications that can be supported by the energy storage unit, systems from even the same technology (such as lithium ion) can be deployed into a variety of different power and energy ratings, with a variety of system design equipment (cabling, HVAC, power electronics, controls, etc.) that can be optimized for different market roles. All of these attributes make the overall architecture design of the system critically important.

Project Level

The goal for an energy storage project development is to develop the highest risk adjusted return possible. Success in operating an energy storage asset can be self-deceiving as projects can operate at a higher risk level than understood; luckily, many time disaster is averted event without knowing there was risk. Project development must therefore comprise both of building up the necessary equipment into a workable capital asset design, reviewing the resulting systems capabilities, and clearly understanding where shortfalls may occur, be they technical, operational, or contractually based.

Operations and Market Strategies: Cell Level

The core operation of an energy storage system is to cycling energy in and out of the unit. While individual energy storage technologies approach this most basic function differently, it is important to recognize what are the leverageable and limiting technical factors that govern how a system built around a particular technology will perform. Other technical factors impact this operation such as the self-discharge rate and issues governing the lifespan of the unit, not just how long it will last, but under what conditions. Coupling these technical factors with the physical form-factor limitations help provide stakeholders with a better understanding of the trade-offs at the most basic building block level for energy storage systems.

Cycling

The central activity for a stationary energy storage system is to transfer energy into and then out of the system to perform some valued application. Moving the energy into and out of the system is known as charging and discharging the system. Depending on the technology in question, there will be a number of technical attributes that will govern how this happens, and thus what usage profile or environmental conditions is best suited for a system built around the technology in question. If the energy storage system is built from chemical cells such as lithium ion or lead, these are connected in series to form modular building blocks to craft larger systems. The cells within the modules are directly connected electrically, and thus each cell will impact the others during charging and discharging, requiring periodic balancing to ensure long life and effective service.

Self-Discharge

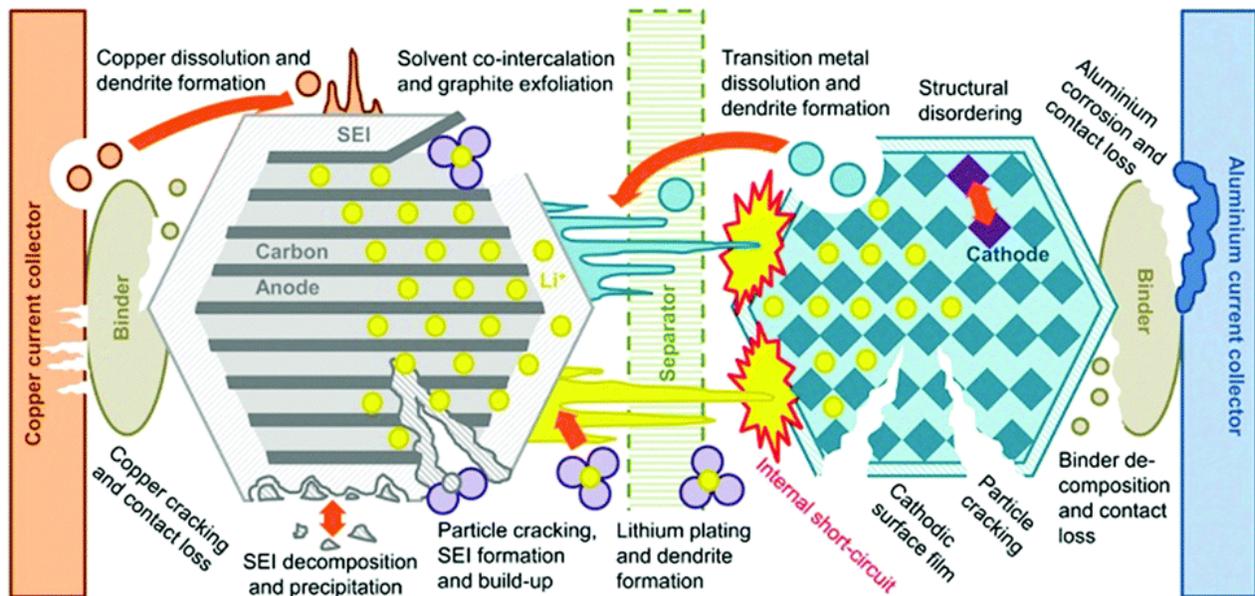
Most interest in energy storage technologies and facilities is generally focused on the active use of the facilities. However, the standby mode of the energy storage facility has an impact on the overall provision of service. The type of technology is critical in defining the impact on the energy rating (kWh) of the unit when not in operation. In general, energy storage systems based on a chemical reaction will have a greater change in status during standby than technologies based on mechanical technologies, for instance.

Energy storage system can lose a portion of their energy capacity through self-discharge. This is primarily an issue with chemical cells, so the discussion will focus these. As the name implies, self-discharge occurs when there is an internal reaction that reduces the amount of stored energy in the cell. This decreases the amount of energy in the cell available for use, so applications such as UPS or intermittent usage for infrequent capacity market uses with long durations of standby service have battery management systems monitor the battery status and perform periodic recharging.

The self-discharge rate of the cell depends on the technology, and increases with temperature, state of charge, and age of the cell. For instance, Lithium-ion cells can lose over 5% of their capacity in the first month, and then 2% or less for subsequent months. Although the rates will vary by manufacturer, LFP cells typically have a lower self-discharge rate than NMC cells. Lead based cells are extremely susceptible to temperature impacts but will average around 5% per month. Finally, NiCad and NiMH can self-discharge upwards of 25% per month.

Lifespan

The lifespan of an energy storage technology depends upon two key avenues: aging of the equipment at rest (a.k.a. calendar aging) and aging of the equipment under use (a.k.a. cyclical aging). There are nearly 20 energy storage technology types, with new ones emerging on a regular basis. However, we can shed additional light on the lifespan of these energy storage technologies by grouping them based on the form how energy is stored: mechanical, electrical, thermal, and chemical energy storage technologies.



Source: Degradation diagnostics for lithium-ion cells¹

Physical Design

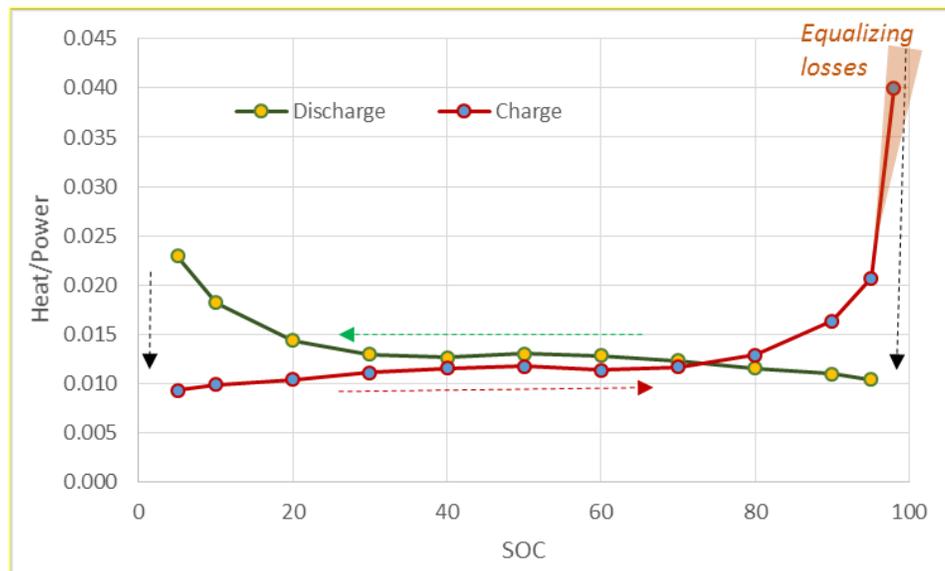
The most basic component of most chemical energy storage systems is the cell. These are too small individually for stationary applications, so they are normally strung together into modules to build systems for stationary applications. Important building blocks for these systems are the Modules, Battery Management Systems, and the Racks.

Operations and Market Strategies: System Level

The system level of an energy storage system is a calculated balance between costs, capabilities, and market requirements. Some of these factors are relatively fixed, such as the capital cost of the equipment, but a surprisingly large amount of the costs is based on the operations of the unit. This can be technical issues such as O&M costs, round trip efficiencies, and thermal management. Other costs and concerns such as degradation and replenishment strategies are greatly impacted by the operation of the unit, but also incorporate a variety of external factors based on the market strategy followed by the owner/operator. Other issues are also heavily impacted by the market strategy of the deployed system, such as the energy management system used, and its capability to interact with local utilities, ISO's and financial markets when dealing with the sale of products and services.

Operations

There are a number of aspects of operations that are impacted by the unit's usage, and thus need to be taken into account for the design of an operating cost issues. The operation & maintenance (O&M) contract maintains the unit in a good working order and many times is required for warranty contracts. Round trip efficiency losses are based on the technology and usage pattern. Thermal management systems are important to mitigate external and internal sources of heat that can reduce the lifespan of the unit.



Source: The importance of thermal management of stationary lithium-ion energy storage enclosures

Degradation

An important aspect of energy storage technology is that the energy storage rating (kWh) can decline over its lifespan. This will vary by technology and can have a material impact on the financial viability of the facility's offtake agreement. For that reason, understanding the reduction in the unit's capacity rating and the strategies to counter it are of a first order importance to the owner/operator.

Degradation is the reduction in the energy rating capacity (kWh) of the battery’s energy storage capacity over set period of time. Therefore, over the life of the system, how much energy can be cycled through will decline (keeping the number of cycles the same). Different energy storage technologies will experience degradation at different rates, with some technologies showing little or no degradation while others experience significantly more. The amount and rate of degradation change is generally based on the technology; those relying on electrostatic, mechanical, or purely reversible chemical reaction will experience little or no degradation during the transformation of the electrical energy. However, this is not true of all chemical storage systems; flow batteries are generally designed for limited to no degradation of energy storage capacity during operation. Cell-based chemical energy systems—batteries—do undergo physical change, and thus degrade during operation, thereby losing some portion of initial battery capacity over their operating life.

Degradation comes through two general pathways: calendar aging and cycle life. Calendar aging accounts for the eventual capacity loss resulting from the slow chemical changes to the battery material and interfaces, reducing or eliminating its reactivity for the reversible storage process. The cycle life aging of the battery is driven by operational factors and also impact the active battery material. Both are impacted by environmental temperature, operating range for the state of charge, charging/discharging rate, etc. The amount of decline will depend on under what conditions the battery is stored, and how the battery is used; depending on these factors, the degradation rate will be faster or slower.

Replenishment

It is critical that project developers incorporate a strategy into the life-cycle plan of the project in order to ensure that the facility will be able to maintain sufficient capacity (kWh) over its lifetime to meet any contract obligations or market strategy requirements. This strategy is increasingly referred to as a replenishment strategy—a plan that takes into account the needs to replenish the battery capacity of the facility as required.

This replenishment strategy is dependent upon several factors that will affect the degradation of the energy storage technology’s capability, including the type of energy storage technology, the expected usage profile, and the environmental conditions where it will operate. It should be noted that a number of technologies do not have significant degradation in the energy capacity of the system over their lifespan, and thus do not require this added cost to support the project outside of the standard maintenance efforts. The rest of this section will deal with technologies that experience degradation like lithium ion or lead.

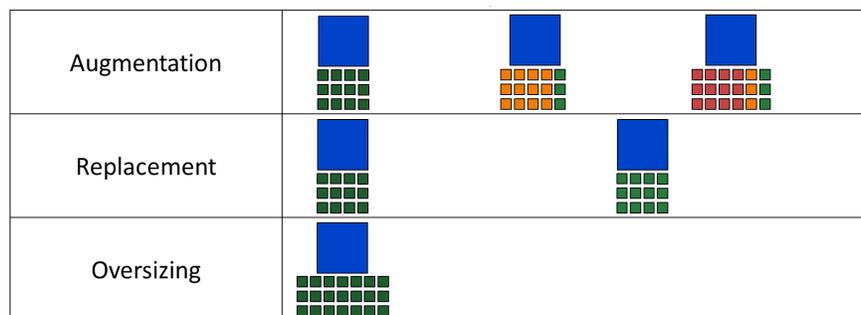


Figure ES-3. Energy Storage Replenishment Strategies

Replenishment strategies attempt to find the least-cost approach to obtain the required capability of the system over its lifespan. The challenge is to map the declining capability of the batteries with the expected usage profile over time to determine how much additional storage capacity must be added. Since the energy rating of a cell-based battery system is expected to decline over time, installing only that which is needed now incurs the least cost for the batteries, but incurs other balance of system costs.

A key point underlying this effort is the technical operating lifespan of the storage asset. Most chemical batteries have a gradual and roughly linear decline in capacity over its lifespan until it reaches a point where the degradation per cycle accelerates. This point has typically been the “technical lifespan” of the cell, historically when the cell has 80% of its capacity remaining. This point has historically been called the “knee.” Advances in battery technology and significantly greater operating experience has extended the roughly linear declining lifespan of cells until the 70% or even 60% remaining capacity is reached.

Three strategies are prominent in most replenishment plans, initial oversizing of the facility, periodic augmentation of the battery capacity, or replacement of the initial capacity. An overall replenishment strategy can incorporate one or more of these individual strategies. The typically strategy is some mixture of initial oversizing—with augmentation occurring a few years into the future. If the facility is designed to have a significantly long life with constant use, a replacement is sometimes called for. All of these milestones are in flux as battery performance continues to improve.

Due to the declining cost of the battery modules, the typical cost minimization strategy is to only incorporate only enough capacity to ensure compliance with the required amount. This strategy thus pushes off into the future as much of the replenishment as possible as future batteries are expected to cost less. Determining the least-cost replenishment schedule will continue to vex many project developers who desire to use the energy storage facility for a number of applications.

Energy Management System

As energy storage systems become more versatile and interconnected with external management systems the control suite of energy management systems is becoming more important. The EMS monitors and manages the real-time operation of the energy storage asset, and is used as the basis for optimizing the performance of the system.

Energy management software is critical achieving a successful energy storage system operation. Typically, there are three components of the energy management software: Market Analytics, Site Controller and Management, and Communication and Portfolio Management. It should be noted, however, that not all software suites have all of these components, due in large part typically to the market focus of the provider.

The market analytics layer provides decision intelligence and critical insights into the physical and economic conditions where the energy storage asset(s) operate. This entire modeling component can quickly become complicated forecasting market prices and strategies in a dynamic environment. Here, data feeds from the software provider’s central hub are evaluated to discern what would be the most profitable and valuable operation in both the short term and long term. This may be one of the most specific and complicated differences between energy storage and other power sector market analytics. Due the inherent limitation of storage capacity and lifespan of the energy storage system, there is always a feedback loop between market strategy, and lifespan/capability of the unit.

The local site control and management layer monitors and manages the energy storage asset at a specific site. The site controller first serves as a single collection point for the performance data of

an energy storage asset. The unit gathers critical status on equipment and performance data of battery and auxiliary components for diagnostic and control. The site controller also handles the controls and coordination of energy storage system dispatch. The site controller can either make autonomous decisions using pre-selected strategy or incorporate user selected input. For both avenues, the site controller will generally be able to provide an optimized performance strategy weighing the short-term economic gain with long-term health and limitations of the batteries, and auxiliary equipment (inverters and HVAC equipment).

The Communication and Portfolio Management layer provides the ability to coordinate one or more independent units for remote monitoring and coordinated market operation. Increasingly, this is including both energy storage and other DER technologies. This Portfolio Management can then communicate with either utility distribution management systems for remote control, or to a trading desk for bidding purposes into an ISO/RTO clearing market for services.

Operations and Market Strategies: Project Level

A successful energy storage project design leverages the capital equipment in the most cost-effective market operation strategy available. This is easier than it sounds. All of the operating characteristics and capabilities provide operational envelope for the project to operate and either support the existing offtake agreements or operate in merchant mode (many times it is both). Although most capital equipment expenses are paid up front, end of life responsibilities will only happen far into the future, with little existing evidence to date as to the validity of the current assumptions. Other project level issues such as operating contracts and risk management strategies will take place over the life of the unit, and thus will need to be evaluated over time as changing usage profiles will affect costs and project risks for a successful operation of the facility.

End of Life

As capital providers learn to account for all components of energy storage project financing, end-of-life costs are becoming an important component to address. Early estimates were sometimes wildly optimistic, but a slow but growing level of experience is providing a more refined range for total costs. For planning purposes, current estimates for the end-of-life costs for a lithium-ion battery system range from 10% to 15% of the initial capital cost of the system. For instance, the battery life-cycle management company Renewance² estimates the cost for dismantling, shipping, and recycling a 10 MWh lithium-ion based project at over \$474,000, or nearly \$50/kWh. These costs will vary by technology and can rise for large scale energy storage systems that have a large portion of civil work.

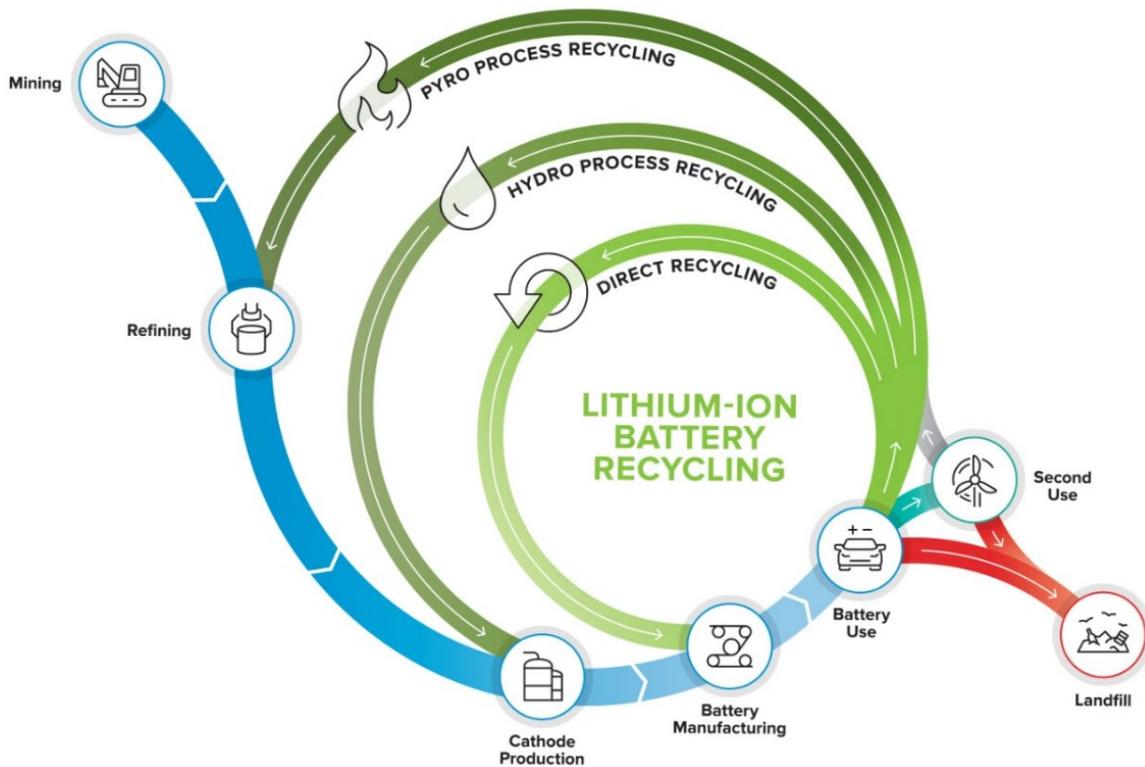


Figure ES-4. Circular Economy Pathways for EV Batteries

Source: ReCell, Argonne National Laboratory

Although the processing costs for removing and dealing with the project’s equipment are becoming more understood, there still remains room for additional cost reductions, and possible reclaimed value from the materials. Currently, low volume of lithium-ion recycling hampers cost reductions through scale, but the increase in vehicle batteries usage promises to warrant additional investment so incremental advanced in current process and automation are expected, with the potential for lower cost process remain as the technology improves. Other markets are a good example that more can be done, as roughly 90% of lead acid batteries are recycled.

The potential value of reclaimed materials continues to be in flux due to a number of issues. First, the capability of the process equipment can generate different quantities of valuable metals. Secondly, the rise in the popularity of LFP based cells is driven by lower initial costs, but also then lack valuable reclaimable materials such as cobalt. The value of recycled materials will never be a deciding factor by developers in choosing a battery supplier, but as the industry matures, it will feed into the overall decision process.

This end-of-life decision contains three parts: Decommissioning, Transportation, and Disposal.

Offtake Contracts

The growth of the energy storage market has expanded the number and type of stakeholders wanting to contract for the benefits of energy storage projects without owning the asset. No single offtake agreement exists for energy storage project financing, leading the energy storage market to borrow or adapt a number of standard contracts for other parts of the electrical power industry,

while making some adjustments for the specifics of the energy storage industry. Off-take agreements provide the stable cash flows critical bankable project financing. The level of revenue certainty is effectively a trade-off between certainty and profitability. Many contracts for entities wanting to utilize the capabilities of assets have the features of contracts such as:

- **Take or Pay Contracts:** Take or Pay Contracts requires the offtaker to pay for the products on a regular basis whether or not the offtaker actually takes delivery of the products.
- **Take-and-Pay Contracts:** Take and Pay Contracts requires offtaker only pays for the product taken on an agreed price basis.

Offtake contracts for energy storage facilities typically follow standard power purchase agreement (PPA) structures as they allow for variability in the underlying contract details based upon an agreed upon performance criteria. There are many criteria to these, including contract terms, fixed and variable compensation components, cost escalators, capacity, range of possible energy throughput, penalties, availability, etc. These areas typically fall into the front of the meter (FTM) market and behind the meter (BTM) market.

As the market continues to evolve, new offtake contracts are expected emerge and evolve. For that reason, current contracts must deal with the potential for change in the regulatory environment where the project operates. The role of the contract is to primarily define the party responsible for any additional charges or change in the performance capability of the project.

Project Contracts

Beyond the critical off-take contracts, a number of other project level contracts are essential for a successful, profitable, and risk minimized operation of an energy storage facility. These include EPC contracts, O&M contracts, warranties, and performance guarantees. These different contracts act as capstone agreement for the particular area of the project in question, requiring a clear understanding of what issues and concerns exist from the module level and system level would impact the project's reliable operation.

Risk Management

Managing a project's financial risk exposure requires a deep understanding of not just technical issues on the equipment and markets, but also their impacts of their operation, and how the various market strategies can impact both potential revenues and costs. There are two areas of risk management strategies where the operations of the project will both be impacted, and impact other aspects of operating the facility: insurance and warranty coverage.

Role For the U.S. Department of Energy

The U.S. Department of Energy has an important role in establishing a foundation of resources, analytics, metrics, and commonality among definitions to supporting improved operations & strategy. As the U.S. Department of Energy puts more resources toward improving the development of energy storage technologies, new and innovative programs are being developed, and existing programs are gaining additional support. Together, this will enable to U.S. Department of Energy to play a crucial role by providing a greater focus on Safety, Performance, Data and Analysis, and overcoming the Project Valley of Death.

Safety

The U.S. Department of Energy has considered Safety to be a critical foundational component of all aspects of energy storage project operation. For the last decade, the U.S. DOE has led the efforts to incorporate safety into all aspects of energy storage technologies and deployments.

Cost & Performance

The U.S. Department of Energy believes that promoting a clear understanding of the cost and performance of energy storage technologies supporting common applications is crucial for customers and stakeholders throughout the Nation. This is no easy task as there are many different types of technology, that come in many different designs and sizes, that need to be optimized sometimes for specific usage profiles. Adding to this complexity is that “how” one uses an energy storage system many times impacts its lifetime performance and subsequent costs.

The U.S. DOE addresses this challenge in a number of ways. First, it sponsors the development of a number of reports and analyses to improve the visibility into the changing cost and performance of energy storage technologies. The DOE also promotes a more detailed investigation into the different possible applications to help define the usefulness of these technologies. Finally, the DOE supports the use of performance analyses and metrics as guides for policy decision making.

State Level Support

The U.S. Department of Energy produces many tools and resources in support of States and utilities incorporating energy storage technologies within their evaluation and planning. These include both efforts targeted at Integrated Resource Plans, and State governmental bodies that are looking to formulate their own plans for guiding energy storage development in their State.

Data & Analysis

Providing clear technical and market data is an essential role for the U.S. Department of Energy as it attempts to help stakeholders and policymakers better insights and strategies to improve the operations of energy storage projects supporting a variety of usage profiles. Critical efforts here include the development of standard and open databases and valuation analysis models.

Industry Analysis

The U.S. Department of Energy supports a variety of industry analysis focused on supporting stakeholders understand the impact of operations and different market strategies have on energy storage projects. Key areas of support include Policy, Market, and Economic Analysis.

Overcoming the Project Valley of Death

Energy storage technologies face a critical hurdle after they prove successful operation of their technology, a project development valley of death. Most are familiar with the technology valley of death, so it is useful to look at that challenge, and see what lessons can be learned. As can be seen in the following figure, the technology valley of death highlights the need for a significant amount of capital resources to maintain even small amounts of progress as it moves through the later stages of the technology development segment. This is driven by the need to scale manufacturing capability, develop larger, more complete systems, and absorb and internalize the lessons learned from failures.

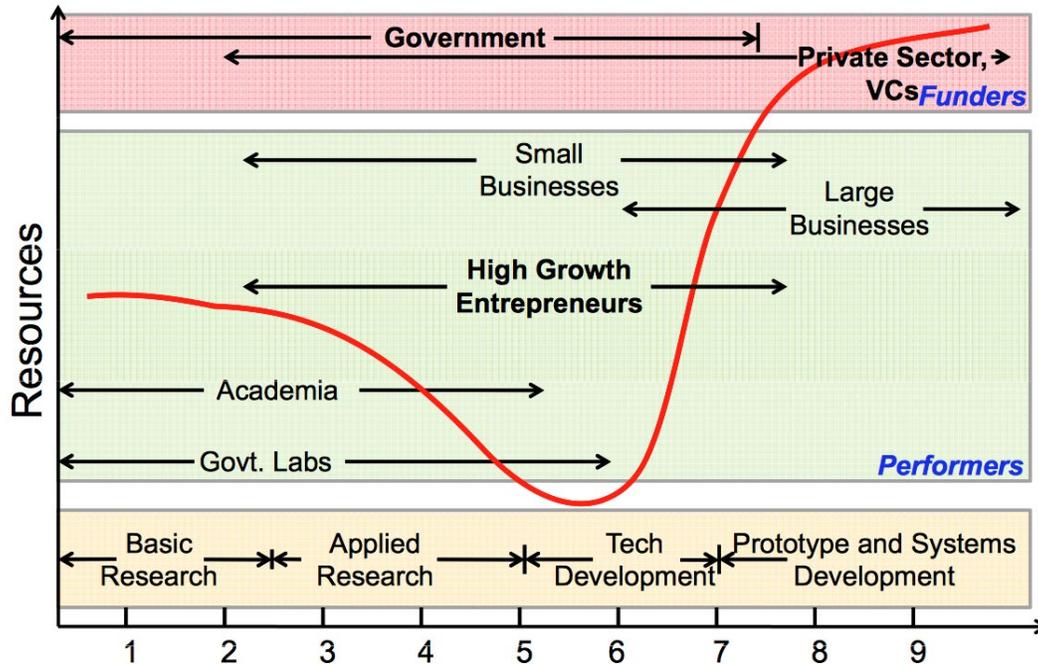


Figure ES-5. Technology Valley of Death

Source: <http://philipleitner.net/technology-readiness-levels-impact-of-science-and-the-valley-of-death/>

After successfully deploying a few demonstration units and initial commercial units, many in the technology development realm consider progress to occur unabated, pulled easily by the demand of the market now that the core technology's future performance has been proven. Unfortunately, this is not the case.

Successfully deploying and operating new technologies is a well-known challenge for groups that own and operate electric power infrastructure like utilities, IPPs, developers, private equity groups, etc. They understand that operators need time to gather operating data to understand both the current costs to operate the units and their performance envelope, and possible future costs and performance capabilities once these lessons have been incorporated back into the OEM and system integrator supply chain, plus additional operating experience to provide a system that can then be integrated into their own operating and maintenance structure. For this reason, capital providers for project development efforts for technologies like energy storage have much in common with VCs trying to fund early-stage technologies and move them to a deployable product stage.

The project development valley of death can thus be seen similarly as the steeply increasing need for investment capital for owners and operators to prove out a successful project cost reduction curve and increasing project performance envelope. Although the sums are much larger, infrastructure-oriented groups like debt providers are typically loath to invest in projects that are not already mature from a project portfolio perspective, leaving the early stage (first 5-10 years) of project deployment to private equity groups willing to take on the higher risk.

The U.S. Department of Energy is well positioned to be an essential player in helping the energy storage project development industry transition to a more mature and less risky status. This effort will take many forms, such as helping the industry to transition from public to private funding, applying lessons learned from solar and wind project development efforts, and identifying and addressing challenges in the energy storage project development market.

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
AC	Alternating Current
ANSI	American National Standards Institute
ARPA-E	Advanced Research Projects Agency-Energy
BESS	Battery Energy Storage System
BMS	Battery Management System
BTM	Behind-the-Meter
COD	Commercial Operation Date
CPUC	California Public Utility Commission
CRL	Commercial Readiness Level
CSR	Codes, Standards, and Regulations
DARPA	Defense Advanced Research Project Agency
DC	Direct Current
DCSSA	Demand Charge Shared Savings Agreement
DER	Distributed Energy Resources
DERMS	Distribute Energy Resources Management System
DOD	Depth of Discharge
DOE	Department of Energy
DRESA	Demand Response Energy Storage Agreement
ECI	Electrical Construction Industry
EOL	End of Life
EPC	Engineering, Procurement, and Construction
EPRI	Electric Power Research Institute
ERCOT	Electric Reliability Council of Texas
ESA	Energy Storage Association
ESCO	Energy Services Company
ESPC	Energy Savings Performance Contract
ESS	Energy Storage Systems
FERC	Federal Energy Regulatory Commission
FTM	Front of the Meter
GADS	Generator Availability Data System
HVAC	Heating, Ventilation, and Air Conditioning
IEEE	Institute of Electrical and Electronics Engineers
INL	Idaho National Laboratory

Abbreviation	Definition
IRP	Integrated Resource Plan
IRS	Internal Revenue Service
ISO	Independent System Operator
ISO	International Organization of Standardization
ISO-NE	Independent System Operator New England
ITC	Investment Tax Credit
kW	Kilowatt
kWh	Kilowatt hour
LBL	Lawrence Berkeley Laboratory
LCOS	Levelized Cost of Storage
LD	Liquidated Damage
LFP	Lithium Iron Phosphate
LPO	Loan Programs Office
MACRS	Modified Accelerated Cost Recovery System
MBTF	Mean Time Between Failure
MESA	Modular Energy Storage Architecture
MISO	Midcontinent Independent System Operator
MW	Megawatt
MWh	Megawatt hour
NEC	National Electrical Code
NECA	National Electrical Contractors Association
NERC	North American Electric Reliability Corporation
NFPA	National Fire Protection Association
NCM	Lithium Nickel Cobalt Manganese Oxide
NRE	Non-Recurring Engineering
NRECA	National Rural Electric Cooperative Association
NREL	National Renewable Energy Laboratory
NTP	Notice to Proceed
NY-BEST	New York Battery and Energy Storage Technology Consortium
NYISO	New York Independent System Operator
NYSERDA	New York State Energy Research and Development Authority
O&M	Operation & Maintenance
OEM	Original Equipment Manufacturer
ORNL	Oak Ridge National Laboratory
PCS	Power Conversion System

Abbreviation	Definition
PJM	PJM Interconnection, Inc.
PNNL	Pacific Northwest National Laboratory
PPA	Power Purchase Agreement
PUC	Public Utilities Commission
PV	Photovoltaic
R&D	Research & Development
RA	Resource Adequacy
RFP	Request for Proposal
ROI	Return on Investment
RTE	Round Trip Efficiency
RTO	Regional Transmission Organization
SBIR	Small Business Innovation Research
SCADA	Supervisory Control and Data Acquisition
SDO	Standards Developing Organization
SGIP	Small Generator Incentive Program (CPUC)
SGIP	Small Generator Interconnection Procedures (FERC)
SNL	Sandia National Laboratories
SOC	State of Charge
SPE	Special Purpose Entity
SPP	Southwest Power Pool
T&D	Transmission and Distribution
TOU	Time-of-Use
TRL	Technology Readiness Level
UL	Underwriters Laboratories
UPS	Uninterruptable Power Supply

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1. CHALLENGES & OPPORTUNITIES

Operations and market strategy is the next critical challenge in the stationary energy storage market. Many early successful market roles of energy storage assets were single application power related activities, such as frequency regulation (FTM) and peak shaving (BTM) which relied on availability and responsiveness of the asset, but could manage with shorter discharge durations, and even significant degradation of the cells without impacting the primary use of the asset too severely. Increasingly, successful market roles for energy storage assets incorporate multiple applications, which both can interfere with the unit's availability with each other's dispatch availability and capability, require a number of other performance characteristics, and balance of use of the asset in the short term vs. long term in order to provision the full contractual obligation of the facility.

The opportunities for project developer lie in the ability to understand how these issues are integrated into the design, operation, and project development of energy storage projects. The challenges and opportunities for energy storage project development incorporates aspects at all levels of the system architecture. At the cell level, technical design and performance attributes of the technology will impact usage. At the system level, system integration capabilities dictate the bankability of the resulting system. At the project level, the ability to support and guarantee off-take capabilities directly impacts the revenue certainty of the unit, and how valuable the project is. Through this framework, it can be seen that all aspects of the design and operational choices impact how a project can be developed, and what it can accomplish.

1.1. Cell Level

The goal for an energy storage technology is to balance the needs and requirements for charging and discharging energy from the core storage device. There are a number of key attributes surrounding this action, that will impact both the design and cost of the unit, and also the capabilities of any system designed around these core technology systems, including the rate of charging, the total amount of storage capacity, the impact of operation on the physical components of the storage medium, etc. These attributes will define basic design challenges for OEMs, but also present some opportunities when comparing different technologies supporting the same application.

1.1.1. Challenges

Challenges arise from design attributes as manufacturers attempt to craft and usable modules that can be incorporated into larger systems. There are a number of challenges at the cell level that will have impact on the system level capabilities, and project level strategies for energy storage deployments. These include OEM manufacturing and performance issues and impacts from unit designs.

- **Design Capabilities:** All energy storage technologies have a variety of technical design attributes and capabilities endemic to the technology, such as energy density, charge and discharge capabilities, etc.
- **Manufacturing:** The manufactured quality of the core cell or module unit will have a direct impact on both the capability and longevity of the resulting systems, but also on the value of the warranty. With the growing scale of manufacturing capabilities of OEMs, there is also a quickly resulting price premium for smaller scale manufactures, reducing these smaller OEMs even further without enhanced quality attributes.

- **Longevity:** The ability of the cell or module to operate for a long calendar or cycle life goes directly to the value of the resulting system and is typically overlooked when discussing the cost of equipment. For instance, if a particular cell costs \$100/kWh and can last for 10 years, and another cell costs \$125/kWh and can last for 20 years, which one costs “more”? This goes directly as to whether people are looking at these systems from a product or project viewpoint.
- **Design Assembly:** The design parameters of the basic energy storage module will impact what scale and capability of the resulting system. Many designs are focused around easily replicable building blocks so systems can be physically designed for a variety of standard market deployment options.
- **Balance of Systems:** The operation requirements of the energy storage modules will have an impact on the supporting equipment necessary to scale the unit. This can be as simple as the weight of the systems, to critical issues such as the cooling requirements based on the amount of heat produced during operation.

1.1.2. Opportunities

Opportunities arise at the cell level through understanding how to best craft and use modular building blocks of the different technologies to leverage the technical advantages inherent in that particular technology. Simple packaging of cells into modules is relatively well understood, but without a clear understanding of possible usage requirements, it is easy to develop modules that do not have sufficient cooling capabilities, or designs that use materials acceptable for infrequent use, instead of constant use. This knowledge is critical as the fundamental capability range of a resulting module is determined by design choices at the cell and subsystem level which can even reduce the usable capacity of a cell significantly below its possible usage.

Key groups able to take advantage of opportunities at the cell level are OEMs and system integrators. OEMs are able to utilize their technical understand of the underlying cell technology to construct modules with superior operating capabilities. System integrators with good technical understanding are also able to construct entire systems that can sustain exemplary performance over its lifespan, allowing both groups to price at a premium. Even if these modules and systems may be higher cost than the market’s cheapest option (albeit marginally more expensive – cost is still the most critical issue), developers and lenders will gravitate to systems built from these higher standards components to reduce design and operation risks which can far outweigh capital cost discrepancies if they cause disruptions in operation or damage to the unit.

1.2. System Level

The goal for an energy storage system is to balance to need to incorporate the most capability into the system at the lowest costs. This goes beyond simple energy rating (kWh) and power rating (kW) as the value in the system is based on one that can be used (a) more often, (b) more dynamically, and (c) safer. Since there are a number of possible applications that can be supported by the energy storage unit, systems from even the same technology (such as lithium ion) can be deployed into a variety of different power and energy ratings, with a variety of system design equipment (cabling, HVAC, power electronics, controls, etc.) that can be optimized for different market roles. All of these attributes make the overall architecture design of the system critically important.

1.2.1. Challenges

Challenges arise from system integration requirements as firms design complete energy storage systems able to accomplish a variety of market applications. There are a number of challenges at the system level that will have impact on the project level capabilities, and project level strategies for energy storage deployments. These include system integration, operational performance metrics such as round-trip efficiency and cooling requirements, and control systems.

- **System Integration:** System integration of even lithium-ion systems is far more complicated than most project financial groups believe. This has implications from the construction through the operational support, including possible limitations in range due to paying for just the bare minimum of HVAC, etc.
- **Round Trip Efficiency:** The round-trip efficiency of the cell or module is based on the technology, but system design is concerned with the overall round trip efficiency at the AC level input. This will incorporate all of the scaling properties of the storage modules through the HVAC and power electronics. Increasingly important is the impact of operations—the rate and duration of charging and discharging—will have on the system. This extends not just to the power load required for the HVAC system, but the increasing evident exclusionary time periods due to heating from operation, thus impacting the dispatch potential of the unit overall.
- **Degradation/Replenishment:** The degradation of chemical cells is based on calendar and cyclical aging. Impacting these two degradation pathways (length of time, # of cycles) is the temperature of the cells, rate of energy transfer into or out of the cell, the state of charge of the cell, age of the cell, etc. As the project financing is based on the estimated capability of the system to provide a specified lifespan for the cells, accelerating degradation must be addressed during operation, else the unit will not support the intended, or contractually obligated, operational role for the facility.
- **Thermal Management:** Thermal management systems are required to maintain the energy storage system within a specified range as thermal generation can derive from either the external environment or from operation. The challenge in maintaining a proper temperature range is based on the type and scale of cooling and how much they will be used. This impacts the cost, but if insufficient equipment is installed or used improperly, then the availability of the storage systems will be curtailed—possibly drastically impacting the operation of the unit during its highest value period.
- **Controls / Communication:** As the value of energy storage projects transitions from direct energy and power rating of the facility to the capability and insightful timeliness, the controls and communication systems rise to prominence. As revenue certainty becomes a critical metric for a project, bankability of capability as a foundation for reliable contracted revenue, the ability of advanced control systems transition from a good to have to a must have.

1.2.2. Opportunities

Opportunities arise at the system level through leveraging system integration design and assembly capabilities for all of the critical sub-systems that comprise an energy storage system: storage modules, HVA, controls, etc. Specifically, the performance and reliability of the system are becoming very important to the bankability of the unit. Bankability rests first on the strength of the system's design, which relies on a deep technical understanding of the capabilities of the sub-systems

in order for system integrators to build the most cost-effective project. The bankability evaluation conducted by 3rd party engineering firms are an essential determinant by project developers when evaluating both the initial cost and ensuring successful operation of the facility over its lifespan.

Key groups able to take advantage of opportunities at the system level are project developers and capital providers. With a clear understanding of the facility's capabilities and limitations, project developers will have a better understanding of how the design capabilities are able to provide the unit advantages in the market during operation. Beyond where to take advantage thought, it will also provide insights into where in the market the system is not suited, so therefore a means to reduce operational risk. Capital providers benefit from this understanding as well. Through a clear understanding of the economic performance estimates provided by the developer, they can better evaluate how this project would fit within their development approach and any existing internal risk adjusted return mandates.

1.3. Project Level

The goal for an energy storage project development is to develop the highest risk adjusted return possible. Success in operating an energy storage asset can be self-deceiving as projects can operate at a higher risk level than understood; luckily, many time disaster is averted event without knowing there was risk. Project development must therefore comprise both of building up the necessary equipment into a workable capital asset design, reviewing the resulting systems capabilities, and clearly understanding where shortfalls may occur, be they technical, operational, or contractually based.

1.3.1. Challenges

Challenges arise from project development efforts when matching the expected operating capabilities of the proposed project with the resulting capabilities of the actual capital equipment that is installed and operated in real life. There are a number of challenges at the project level that will impact not just the operations, but the cost of the facility, shifting the resulting profitability of the project. Key among these include end of life, off-take contracts, EPC contracts, and warranties.

- **End of Life:** End of life responsibilities are an emerging area of project financing costs. Previous estimates have ranges from unrealistic “residual value” estimates (good for NPV), but increasingly better estimates are emerging for a realistic cost that should be address. Only after a number of projects have gone through this process will we know if there are additional costs and liabilities that need to be addresses, and who will be responsible for them.
- **Offtake Contracts:** Structuring revenue contracts define the process through which revenue is generated. Since different technologies and system designs have different operational qualities, it is important to clearly understand where the strengths of different technologies lie, and what potential challenges some resulting projects may have when delivering to a specific offtake contract.
- **EPC Contracts:** The installation design and construction of energy storage systems have an incredibly big impact on the operation and viability (both long term and capability) of the system. Ensuring that the EPC vendor chosen has significant experience with both the technology and deployment goal of the system is critical.

- **Warranty:** Warranty contracts ensure that there are financial backstops to the technical assurance of capability of the equipment. With the increasing comfort of developers utilizing lithium-ion system, warranty coverage is still a large concern from large customers such as utilities that need installed equipment to have clear lines of responsibility in the event of a disruption, and emerging energy storage technologies that need additional assurance that there are additional resources standing behind the emergent OEM.

1.3.2. Opportunities

Opportunities arise at the project level through understanding the project development process and leveraging those insights into managing risks that impact the legal and contractual standing of the project. Critically, insightful market analysis of potential off-take contracts or merchant roles will be essential in determining the design, scale, and operational requirements of the facility. This is becoming increasingly important as wholesale market revenue opportunity for energy storage are increasingly centered on the ability to support dynamic operations rather than repetitive charging and discharging (in and out of an off-take contract). Understanding the interconnected nature of the EPC contract and warranty coverages ensure that the project develop process goes through quickly so the unit can begin operation without delay. This is very important with regards to codes and standards that impact the deployment and operation of the unit.

Key groups able to take advantage of opportunities at the system level are project developers and capital providers. With a clear understanding of the facility's legal and contractual framework, project developers are able to present a project revenue opportunity that incorporates needed risk management strategies that potential investors will require. Capital providers will have an easier internal approval evaluation if the project development legal and contractual package incorporates proper siting and insurance foresight in order to mitigate possible downside risks.

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2. OPERATIONS & MARKET STRATEGY: CELL LEVEL

The core operation of an energy storage system is to cycle energy in and out of the unit. While individual energy storage technologies approach this most basic function differently, it is important to recognize what are the leverageable and limiting technical factors that govern how a system built around a particular technology will perform. Other technical factors impact this operation such as the self-discharge rate and issues governing the lifespan of the unit, not just how long it will last, but under what conditions. Coupling these technical factors with the physical form-factor limitations helps provide stakeholders with a better understanding of the trade-offs at the most basic building block level for energy storage systems.

2.1. Cycling

The central activity for a stationary energy storage system is to transfer energy into and then out of the system to perform some valued application. Moving the energy into and out of the system is accomplished through charging and discharging the system. Depending on the energy storage technology in question, there will be a number of technical attributes that will govern how this happens, and thus what usage profile or environmental conditions is best suited for a system built around the technology in question.

If the energy storage system is built from chemical cells such as lithium ion or lead, these are connected in series to form modular building blocks to craft larger systems. The cells within the modules are directly connected electrically, and thus each cell will impact the others during charging and discharging, requiring periodic balancing to ensure long life and effective service.

2.1.1. Charging & Discharging

The fundamental aspect of cycling a battery is the act of charging and discharging the cell. There are a number of technical characteristics of charging and discharging that will impact how a complete system will act and make a particular system more or less suited for a particular application.

Three aspects deserve closer attention to understand their impact, including round trip efficiency, the state of charge range, and the rate of charging and discharging (C-Rate).

2.1.1.1. Round Trip Efficiency (RTE)

The round-trip efficiency (RTE) of an energy storage system is the representation for the effectiveness of the system to convert electrical energy into the energy storage medium and back again. There are two components, the charging rate efficiency and discharging rate efficiency that are multiplied together to provide the round-trip efficiency. Any type of self-discharge loss (from the energy storage medium when charged) is generally not included in this calculation. The impact of round-trip efficiency on operating costs will be discussed in greater detail in Section 3.1.2.

Examples of some typical round-trip efficiencies for different energy storage technologies can be seen in the following table (with the caveat that the actual RTE of a system will depend upon a host of factors):

Table 2-1. Round Trip Efficiencies (RTE)

Technology	Abbreviation	AC:AC RTE (%)
Pumped Hydro Storage	PHS	70% - 80%
Compressed Air Energy Storage	CAES	50% - 70%
Advanced Compressed Air Energy Storage	ACAES	70%
Liquid Air Energy Storage	LAES	60% - 75%
Gravity Energy Storage	GES	80% - 85%
Sodium	Na	75%
Flow Battery: Vanadium	FBV	70% - 75%
Flow Battery: Zinc Bromide	FBZnBr	70%
Flow Battery: Iron	FBFe	70%
Flywheel: Long Duration	FWLD	90% - 95%
Flywheel: Short Duration	FWSD	70% - 80%
Lithium Ion: NMC	LiNMC	80% - 85%
Lithium Ion: LFP	LiLFP	80% - 85%
Zinc	Zn	70%
Lead	Pb	60% - 75%

Source: Mustang Prairie Energy

The RTE of a particular energy storage system will be dependent upon a number of issues.

- First is the technology in question. Some technologies have a higher range of potential conversion efficiency than others, with different RTE at different rates of energy conversion. Typically, those relying on mechanical conversion can have a lower potential rate than that of a chemical process, with the highest being electrostatic or electromagnetic storage.
- Secondly, it depends on the physical design of the energy storage system. For instance, chemical cells are crafted into modules and then racks, each layer causing an additional (but typically small) reduction in efficiency. Other technologies such as mechanical or flow battery systems are designed at the complete DC system level.
- Third, the balance of system of the energy storage system will have an impact on the overall RTE level. These additional components are primarily the power conversion system, and the HVAC unit. Power electronics typically have conversion efficiencies of 95%-98% or more (each way), so will have a small impact on the overall system's efficiency. These systems will experience significantly less efficiency conversion beginning below 20% load, reaching around 90% efficiency at 10% load, and dropping off faster as the throughput declines. HVAC losses are governed by need to keep the batteries between 20°C and 25°C—the

higher the ambient temperature, the greater this parasitic load will be, reducing overall conversion efficiency.

- Finally, the usage profile will impact efficiency of operation. Each energy storage technologies also have a “sweet spot” for efficient operation, with outside of this being lower.

The level of RTE will impact the choice of application profile. For instance, energy storage technologies with low RTE typically need to be focused on larger scale (MW) and longer duration deployments to overcome to losses in conversion. Systems with higher RTE can be used at smaller scale with shorter durations as more energy is available to be utilized in a hopefully profitable application.

2.1.1.2. Depth of Discharge (DoD)

During the operation of an energy storage system, the depth of discharge (DoD) utilized can have an impact on both the applications attempted, and the life of the system. The depth of discharge is the ratio of the discharged energy to the total amount of energy storage in the system. Individual technologies are able to discharge different amounts of energy without negative impact. For instance, mechanical and flow battery systems are typically able to discharge 100% of the capacity in the system with no little to no impact on the storage medium.

Chemical cell batteries will typically not discharge fully as the chemical reaction at very low states of charge can damage the cell. (The State of Charge (SOC) is the specific amount of energy in the system at any given time as compared to the total amount possible, given in a percentage.) For instance, a lead battery will have a specific cycle-life if discharged to 70% of capacity but will experience a cycle life improvement of over 33% or more if only discharged to 50%. Lithium cells are able to discharge to a far greater extent, although it depends on the chemistry (and OEM), with NMC based cells discharging around 80% to 85% (and increasing) and LFP based cells discharging up to 100% based on design and quality of manufacturing.

The energy available for cycling will directly affect the applications that are cost effective, impacting both the cycle cost of energy, and what is available for work. Since the capital cost of the facility is fixed, the amount of energy cycled through the system will directly impact levelized cost of storage (LCOS) based calculation. Therefore, technologies that are able to discharge 100% of the energy, and that separate the power and energy rating, are positioned to have a lower cycled cost of energy than shorter duration technologies that cannot discharge their full capacity.

Not to be overlooked is the impact of the availability of energy left in the system for work. Energy storage systems are most valuable in a fluctuating market where shorter duration activity can have a higher value than long duration of commodity like dischargers. In today’s increasingly interactive market, the value of energy is dynamic, not a static average value. Therefore, being able to fully discharge an energy storage system gives more revenue generating opportunity to the system than one that is only able to discharge 50% of its rated capacity.

2.1.1.3. Charge/Discharge Rate (C-Rate)

Energy storage systems (primarily chemical cell-based batteries) use the term C-Rate to normalize the charge/discharge capability of different technologies against their capacity. Specifically, the C-Rate is a measure of the rate at which a cell is discharged relative to its maximum capacity. For instance, charging or discharging a battery at a 1C rate means that the battery is fully charged or discharged in 1 hour. If the C-Rate is 2C, then the process is completed in 30 minutes, and if at a

C/4 Rate, the process is completed in 4 hours. The following table provides a description of different C-Rates:

Table 2-2. Battery C-Rate

C-Rate	Time
5C	0.2 Hr
2C	0.5 Hr
1C	1 Hr
0.5C or C/2	2 Hr
0.2C or C/5	5 Hr
0.1C or C/10	10 Hr
0.05C or C/20	20 Hr

Source: Mustang Prairie Energy

This characteristic is important to the physical health and operational strategy of the energy storage system. Different technologies are affected by C-Rate changes in different ways. Some, like mechanical ones are designed around specific physical operational limits, and thus do not have any ability to discharge at higher C-rates than those that are designed into the system.

Chemical batteries are typically more impacted by the change in C-Rates as the chemical reactions that takes place during charging and discharging is based on the movement of ions in the cell. If this process very rapidly—a high C-Rate—this can physically damage the cell, reducing its lifespan and also the total amount of energy that could be stored in the cell.

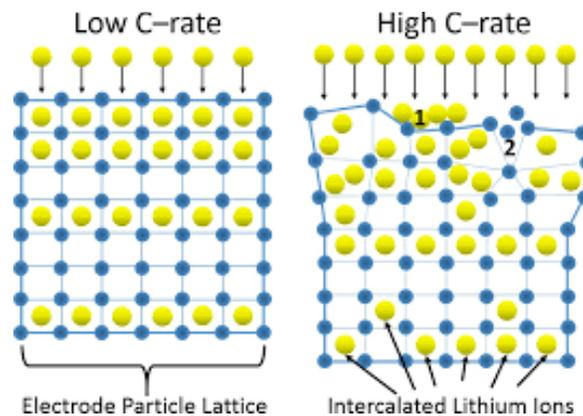


Figure 2-1. High C-Rate Impact on Lithium-Ion Battery

Source: Strategies to limit degradation and maximize Li-ion battery service lifetime - Critical review and guidance for stakeholders³

Individual energy storage technologies will be impacted by these attributes differently which will impact their optimal usage profile. For instance, the energy rating of lead batteries is typically rated at a C/20 rate (0.05C). Shifting this to a C-rate more typical of stationary storage, say C/4 or C/2, will significantly reduce the energy rating capacity (kWh or Ah) of the battery and its lifespan. In this regard, Lithium-ion cells are relatively more tolerant for use along a range of discharge rates, although for sustained high C-rates usage, it is advised to utilize a power-oriented cell (oriented into higher c-rates) instead of an energy cell (oriented towards more energy and longer life).

2.1.2. Cell Balancing

It is important to maintain the state of charge of cells connected in series in an equal balance during operation to prolong life and ensure safety of operation of the cells. Cell based energy storage systems align the cells in series to construct modules (to increase the voltage to a usable level for the larger system architecture), which are the building blocks for different system designs. The cells in each string (those directly connected to each other in series) are electrically connected to each other, meaning they will directly affect each other during charging and discharging. When charging a string of batteries, the weakest string in the cell (highest internal resistance) will experience a higher voltage than the rest of the cells in the string at full charge. Continuous overcharging further increases the internal resistance, raising its temperature, and leading to more cell degradation.

This imbalance can be present from the very beginning of operation, as the initial minute differences in cell capacity are typically due to slight material differences, impurities, manufacturing variances, slight assembly irregularities, and differing impact from environmental conditions on the modules. Over time and cycling, these variations will lead to a wider and wider difference in cell performance and capacity level if not corrected. This situation is self-reinforcing, as once the cell begins to weaken and raise its internal resistance, it is exposed to increasingly higher voltage during charging, which makes it degrade even faster.

Not all battery chemistries are affected in the same manner. Since lithium-ion cells are the most prevalent, the majority of the discussion will be focused on them. However, it is important to note that other cell-based technologies such as NiMH, NiCd, and lead are far more tolerant of overcharging. Other technologies such as flow batteries do not need similar balancing requirement at all.

There are two strategies to enable a cell balancing strategy: active balancing and passive balancing.

2.1.2.1. Active Balancing

The first method of cell balancing is active cell balancing. Here, capacitors are embedded in the module circuitry are used to actively move energy from one cell to another to ensure equal cell capacity. This typically happens at the “top” of the cycle when the first cell reaches full capacity. In this process, energy is removed from the cells with the highest capacity first and routed to the cell with the lowest charge. This process is continued until all cells have the same energy capacity.

This process does present problems to the system operator. This process typically only removes a small amount of energy each cycle using the capacitor. This could lead to a process of many hours, especially with a large number of cells and if they are out of balance significantly. If a significant amount of transport is required, then the small resistance of the intermediate storage medium (usually capacitors) will lead to loss of energy in the system and a production of heat.

Variants of this method also consist of using the module circuitry to bypass the highest capacity cells during charging. This can save on time and energy but requires additional measurement and control capabilities in the battery management system.

2.1.2.2. Passive Balancing

Another type of cell balancing technology is called passive cell balancing. Here, resistors are embedded in the module circuitry to bleed off power from the cells with the highest capacity until it reaches the capacity of the cell with the lowest capacity. This process continues until all of the cells have the same energy capacity.

This method has similar issues as in the active balancing method in that it can take a long time, in fact, this process usually takes even longer. This process also converts a large amount of energy to heat which is very bad for the health of the batteries. It is the easiest cell balancing strategy, but possibly very detrimental to the system as a whole over the life of the system.

2.2. Self-Discharge

Most interest in energy storage technologies and facilities is generally focused on the active use of the facilities. However, the standby mode of the energy storage facility has an impact on the overall provision of service. The type of technology is critical in defining the impact on the energy rating (kWh) of the unit when not in operation. In general, energy storage systems based on a chemical reaction will have a greater change in status during standby than technologies based on mechanical technologies, for instance.

Energy storage system can lose a portion of their energy capacity through self-discharge. This is primarily an issue with chemical cells, so the discussion will focus these. As the name implies, self-discharge occurs when there is an internal reaction that reduces the amount of stored energy in the cell. This decreases the amount of energy in the cell available for use, so applications such as UPS or intermittent usage for infrequent capacity market uses with long durations of standby service have battery management systems monitor the battery status and perform periodic recharging.

The self-discharge rate of the cell depends on the technology, and increases with temperature, state of charge, and age of the cell. For instance, Lithium-ion cells can lose over 5% of their capacity in the first month, and then 2% or less for subsequent months. Although the rates will vary by manufacturer, LFP cells typically have a lower self-discharge rate than NMC cells. Lead based cells are extremely susceptible to temperature impacts but will average around 5% per month. Finally, NiCad and NiMH can self-discharge upwards of 25% per month.

2.3. Lifespan

The lifespan of an energy storage technology depends upon two key avenues: aging of the equipment at rest (a.k.a. calendar aging) and aging of the equipment under use (a.k.a. cyclical aging). There are nearly 20 energy storage technology types, with new ones emerging on a regular basis. However, we can shed additional light on the lifespan of these energy storage technologies by grouping them based on the form how energy is stored: mechanical, electrical, thermal, and chemical energy storage technologies.

2.3.1. Mechanical Storage: Aging & Failure Modes

Mechanical energy storage technologies do not typically experience significant degradation in either their power or energy rating over time. Some examples of these technologies are pumped

hydropower storage, gravity energy storage, etc. These technologies are typically designed at the project level, making all parts of the facility incorporated into the aging and potential points of failure evaluation.

The lifespan of these technologies is based on the wearing of the mechanical and electrical components. Therefore, the usable lifespan of these technologies is on the order of many decades as both calendar and cyclical aging impacts are addressed through normal maintenance, and periodic replacement of key components. The energy storage capacity of these technologies is based on moving mass (water, air, etc.) so any leakage can simply be replaced leaving no real degradation of the energy rating during the lifetime of the unit.

2.3.2. Electrical Storage: Aging & Failure Modes

Electrical energy storage technologies can experience some degradation in their energy rating over time. Some examples of these technologies are supercapacitors or superconducting magnetic energy storage (SMES) units, etc. These technologies can either be designed at the cell (supercapacitor) or unit (SMES) levels, leaving the energy storage medium critically important with regards to the aging and potential points of failure evaluation. Temperature, voltage, and current are the key attributes driving the aging process.

The lifespan of supercapacitors is based on chemical change/breakdown of the core material, but these technologies typically have lifespans measured in the 100's of thousands of cycles or more and 10 years. At this point, typically the supercapacitor will experience some fade over time, leaving roughly 80% of its energy storage capacity at the end of this period. However, individual OEM design, material selection, and manufacturing processes will create a range. The energy storage capacity of these technologies is based on the electrostatic capability the materials.

2.3.3. Thermal Storage: Aging & Failure Modes

Thermal energy storage technologies do not typically experience significant degradation in either their power or energy rating over time. Two main types of thermal energy storage technologies exist, either storing heat, or cold. Examples of heat storage would be molten salt or graphite bricks, while examples of cold storage would be ice storage technology. These technologies are typically designed at the project level, making all parts of the facility incorporated into the aging and potential points of failure evaluation. The core technology storing energy generally utilizes materials that can phase change, incorporating latent heat as part of the energy storage process, or a material that can withstand a very large temperature range.

The lifespan of these technologies is based on the wearing of the mechanical and electrical components, and the breakdown of the thermal storage material. Therefore, the usable lifespan of these technologies can be 10 to 40 years as both calendar and cyclical aging impacts are addressed through normal maintenance, and periodic replacement of key components. The energy storage capacity of these technologies is based on thermal storage capacity of the material, so any reduction in capacity of the energy storage medium can simply be replaced leaving no real degradation of the energy rating during the lifetime of the unit.

2.3.4. Chemical Storage: Aging & Failure Modes

Chemical energy storage technologies typically experience degradation in their energy rating over time—the degree to which is based on their usage profile and conditions. Some of the more common examples of these technologies are lead batteries and lithium-ion batteries. These

technologies are designed at the cell level, focusing aging and potential points of failure at the OEM manufacturer and design.

The lifespan of lithium-ion batteries is based on chemical change/breakdown of the different components of the cell—anode, cathode, separator, electrolyte, current collector, housing, etc., makes defining a specific lifespan for the exact type of each component overall impossible, as there are a variety of materials for the different components that greatly affect performance and aging. However, most lithium systems are designed with a minimum of 10 years life expectation, with many being designed for 20 years of operation (based on a one cycle per day usage pattern). This provides a cycle life of anywhere from 3,500 cycle to 7,000 cycles, with OEM design, material selection, and manufacturing process widening that lifespan further on both ends. The degradation is generally linear for most of the operating life, with an increase in the degradation rate as the cell is close to its end of life past the knee point.

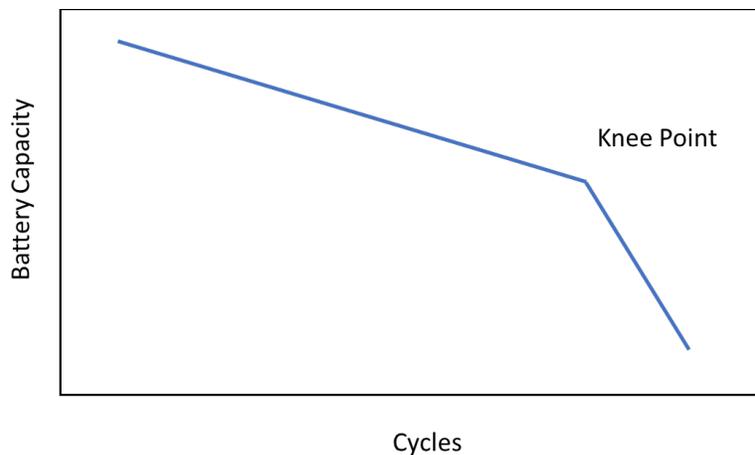


Figure 2-2. Lithium-Ion Battery Aging: Acceleration Near End of Life

Source: Mustang Prairie Energy

The reduction in the capacity of the cell comes through specific degradation of either the structure of the component materials themselves, or the interface between the components. Although ageing impacts can occur over the life of the unit when the cell is not being used, cycling power in and out of the cell will accelerate the cells aging. The degree to either the calendar or cyclical aging will advance is driven by conditions such as temperature, voltage range, current, depth of discharge, state of charge, etc. are the key attributes driving the aging process. A brief overview of all of the chemical cell degradation pathways is seen in the following graph.

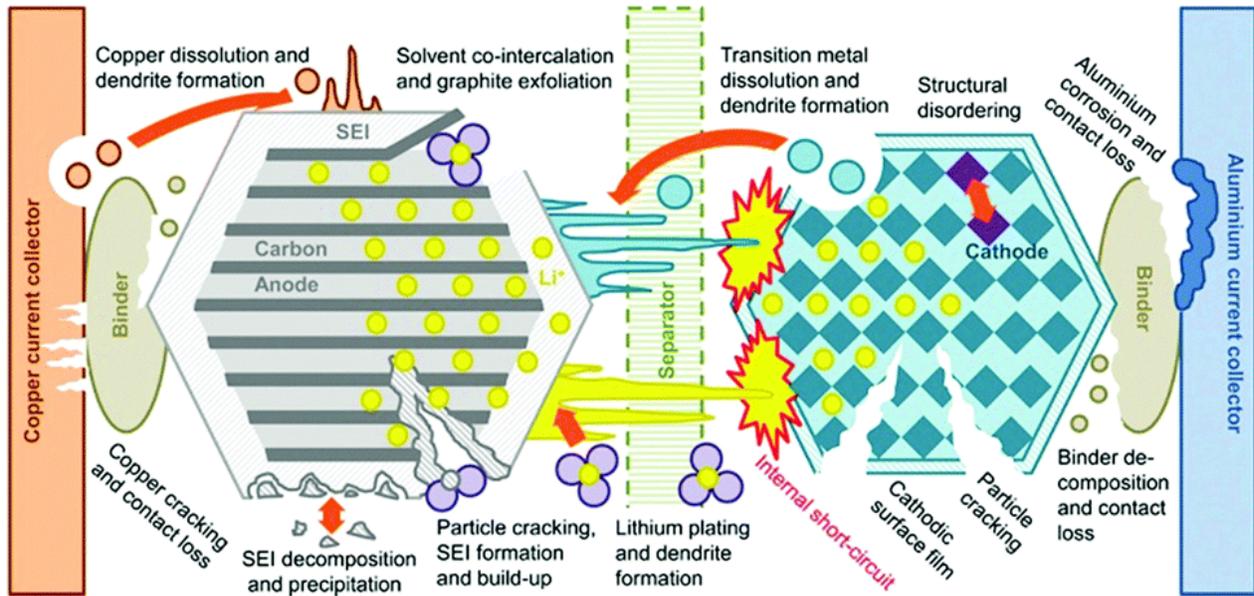


Figure 2-3. Lithium-Ion Failure Modes

Source: Degradation diagnostics for lithium-ion cells⁴

2.3.5. Chemical Storage (Flow Batteries): Aging & Failure Modes

Flow batteries are chemically based energy storage technologies that do not typically experience significant degradation in their energy rating over time. A number of the different technologies do have a slight reduction in the energy rating of the system over time, but this is generally corrected in the O&M effort through adding small amounts of additional electrolyte. As opposed to cell-based chemical batteries, flow batteries are designed at the complete DC energy storage system.

The lifespan of a flow battery is based on the mechanical wear and breakdown of the different components of the system including tanks, pumps, piping, separators, etc. During the reversible operation, only the electrolyte is being impacted, allowing for a significantly larger design energy throughput than chemical cells systems. Annual maintenance replaces equipment components, giving the overall design life of the system upwards of 20 years.

2.4. Physical Design

The most basic component of most chemical energy storage systems is the cell. These are too small individually for stationary applications, so they are normally strung together into modules to build systems for stationary applications. Important building blocks for these systems are the Modules, Battery Management Systems, and the Racks.

2.4.1. Modules

Modules are composed of individual batteries in strings and protection equipment that provide system integrators a standard building block to compose larger systems. This standard design allows different cell designs (and chemistries) from different OEMs to be built around easily handled components to speed the construction of these larger units. Besides being standardized in size (by

OEM), they also allow for a standardized electrical connection, communication, and thermal management.

This level of standardization is important as different battery manufacturers will continue to design their systems around different format sizes and need a way to provide commonality for ease of use by system integrators. Packaging costs will vary, but a typical rule of thumb will have it range to usually equal to 25% to 33% of the battery cell cost (on a \$/kWh basis).

2.4.2. Battery Management System (BMS)

A Battery Management System (BMS) is an electronic control system that ensures a safe and reliable operating environment for the battery modules. Battery OEMs typically provide these units as they are core and critical to the operation of the battery modules. The BMS is typically designed so that it manages a number of individual battery modules, with the number varying depending on the capability and level of control required.

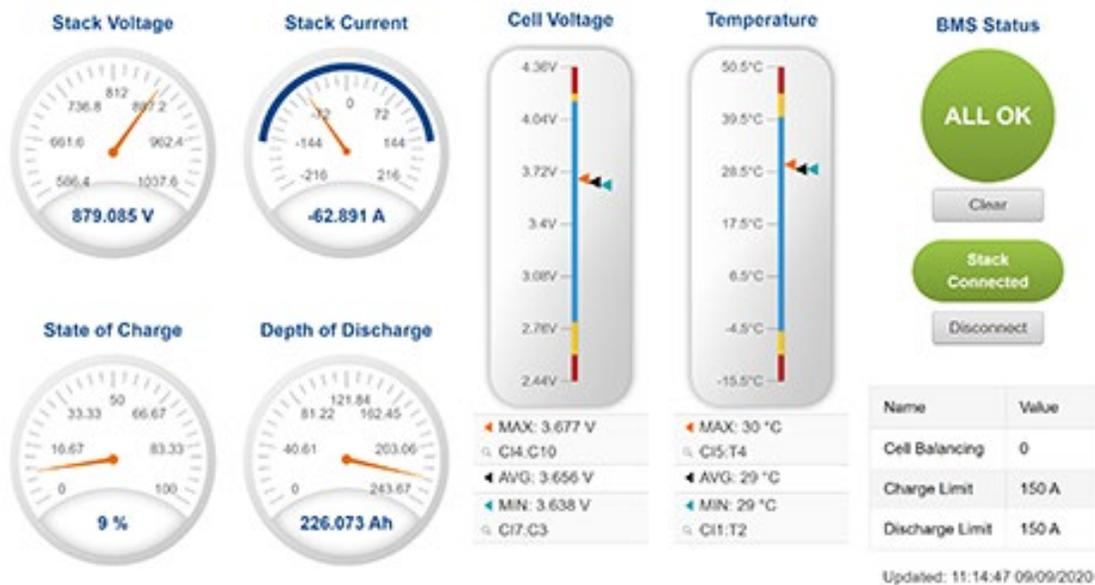


Figure 2-4. Battery Management System

Source: Nuvation Energy

One key function of the BMS is to monitor and log environmental conditions and operating parameters from the modules. This includes temperature, voltage and current levels. This information is important to maintain for regular services, as well as to conform to warranty requirements covering the battery systems.

Using the monitored data, the BMS also controls the environmental conditions and operations of the battery modules. The environmental conditions are managed through controlling the thermal management system to keep the battery modules within a preset range as either external conditions or operations threaten to raise the temperature above a set point where prolonged exposure will damage the cell; the unit also ensures that the modules are kept warm enough in colder climates.

Although BMS units have a multiple of capabilities, three are critical to the safe operation of the battery modules. First, the BMS manages the charging and discharging of the batteries and ensures the rate falls within acceptable parameters. Secondly, the BMS protects the batteries from short circuits and operating outside of safe operating ranges (including over charging, over-current protection, and voltage management). Finally, the BMS is responsible for ensuring that the cells in the modules remain balanced at the same state of charge or voltage as imbalances between the cells on the same string can lead to a reduction in the cell's cycle life (see Cell Balancing).

The BMS utilize a standard communication protocol for communication to relay information and controls to the site controller. Typically, this has been a Modbus TCP protocol, but efforts by a group of energy storage OEMs, system integrators, and utilities developed the Modular Energy System Architecture (MESA) Standards Alliance to support the interoperability of distributed energy resources, with a focused effort for deployed energy storage assets.

According to the MESA Standards Alliance⁵, The MESA Standards combines two international standards: IEC 61850 and IEEE 1815 (DNP3) by mapping the IEC 61850-7-420 semantic data model standard for DER to the widely used IEEE 1815 (DNP3) protocol standard, thus creating an interoperable profile of DER functions, monitored information, and control commands. MESA-DER supports all the IEEE 1547 and California Rule 21 DER functions as well as additional market-based DER functions to support utility grid safe, reliable, and efficient operations. In addition, MESA-DER covers the data exchange requirements for ESS configuration management, including ESS role-based access control (RBAC) for different ESS operational states. The MESA-DER mapping is defined in the DNP3 Application Note AN2018-001.

2.4.3. Rack

The rack (or sometimes rack cabinet, or tower) design is adopted from the telecommunication and data center electronic equipment industries. It is a standardized frame that can hold 19-inch-wide components. Individual battery modules are then inserted and bolted into the rack. The height of each battery modules is standardized as a multiple of 1.75 inches, commonly referred to as one rack unit (U) in height. Typically, racks have been 42U tall, but other heights are possible based on height availability. These racks then incorporate a number of battery modules and BMS units that can easily be installed in either a standard container enclosure, or free standing in an interior of a building.

These racks are then a modular building block to develop larger energy storage system in a systemic way. Integration costs will vary, but a typical rule of thumb will have this cost range to usually equal to 25% to 33% of the module price (on a \$/kWh basis). The move towards custom enclosures allows for the retention of the rack concept, but tailors the size to fit the specialty enclosure / specific energy storage rating of the unit.

2.4.4. Enclosures

Enclosures protect energy storage systems and related electrical equipment to ensure the security of the unit and it stays in good working order. The selection of a particular enclosure size and type will impact both usage needs and cost.

2.4.4.1. NEMA Rating

A standard classification for electrical enclosures⁶ has been developed by the National Electrical Manufacturers Association (NEMA). This rating allows for the proper selection of the enclosure based on physical and environmental concerns and requirements.

- **NEMA 1:** Designed for indoor use and provides a minimal physical barrier against incidental access of foreign material (falling dirt).
- **NEMA 2:** Designed for indoor use and provides a minimal physical barrier against incidental access of foreign material (falling dirt) and light splashes of water.
- **NEMA 3:** Designed for indoor or outdoor use and provides a minimal physical barrier against incidental and access of foreign material and light splashes of water. This level also provides protection against windblown dust, rain, snow, etc. and the formation of exterior ice.
- **NEMA 4:** Designed for indoor or outdoor use and provides a minimal physical barrier against incidental and access of foreign material and light splashes of water. This level also provides protection against windblown dust, rain, snow, etc. and the formation of exterior ice and hose directed water.

2.4.4.2. Sizing / Design

Enclosures can either be constructed to a standard size, or be specialty built to a particular size. When choosing the outside dimensions, the scale of the energy storage system intended is obviously important, but there are other considerations. Spacing for ventilation and safety are required. Chief amongst the regulations is NFPA 855⁷ (Standard for the Installation of Stationary Energy Storage Systems), which limits each cabinet to only 50kWh of battery storage and requires 3 feet of spacing on each side. An exception to this Standard allows for higher density design if the unit is successfully tested against UL 9540A (Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems). For energy storage technologies based on a liquid electrolyte, spill containment would also be required.

Generally, the construction of the enclosure follows one three typical designs.

- **Cabinet:** Metal cabinets are constructed to house the batteries and electronics, coming in different sizes. These cabinets are provided different ratings according to a NEMA standard based on the level of security and protection of the components housed inside the unit.
- **Container:** Containers are built on the standardized shipping containers but incorporate a significant upgrade of electrical and HVAC components. These can come in a variety of lengths, including 10', 20', 40' and 53'; most prevalent are the 20' and 40' varieties. Earlier designs had a central isle for access of the batteries, but modern design allow for access via side-doors for individual racks.
- **Purpose-Built Enclosure:** As the energy storage industry has evolved, the need for a more flexible and low-cost deployment option has risen. This has led to the rise of modular units of 500 kWh to 1 MWh that can be more easily manufactured and deployed more quickly and at scale.

2.4.4.3. Attributes

Enclosures provide a number of important attributes to ensure the proper safe operation of the unit over its lifespan.

Enclosures provide a wide range of environmental and climate controls for the system. This is a critical function as unit longevity and compliance with warranty requirements are directly tied to maintaining the unit within a specified temperature range through the use of HVAC systems; typical

designs for lithium-ion systems have traditionally use air handling systems but are increasingly using liquid cooling due to the rising heat load and space limitations. Unit designs can incorporate a variety of ventilation and insulation depending on the deployment zone and usage rate of the system.

Enclosures provide a critical component of the safety and security for the unit. Depending on the NEMA rating, the unit will be able to sustain deployment in a variety of locations. Critically, the enclosure provides physical separation between the interior electrical components and personnel not authorized to access the unit. They are also an essential component of the fire suppression strategy, by limiting the propagation of a fire from one unit to adjacent systems.

Finally, enclosure design provides for the easy access of the interior. Traditionally designed for only a single point of access (door) to the interior, enclosure designs have migrated to access panels to reach particular components from the outside, preventing constant egress of personnel inside the unit. By designing the interior components needed more frequent maintenance and replacement near the access points, activity inside the unit can be kept to a minimum. In addition, access points allowing ease of inspection of critical systems also prevents possible damage from inspections requirements to investigate far into the unit.

2.4.4.4. Cost Impacts

Since all capital costs are being scrutinized, the cost of the enclosure is being reviewed as to what is actually needed for the project in order to reduce costs. An energy storage system's enclosure strategy has an impact on more than just the cost of the enclosure. The scale and complexity of the system impacts a number of cost items, from capital costs, design engineering, the EPC costs.

The design of the enclosure is always a balance between how much storage you can fit in each container, vs the cost of the container. Historically, system integrators utilized enclosures built around standard shipping containers, usually either a 20' (1 MWh to 2 MWh) or 40' (3 MWh to 5 MWh) variants. Recently, a growing number of system integrators are designing a standardized purpose-built container that would hold 500 kWh to 1 MWh.

The weight of the batteries in the various designs have a significant impact on a number of cost issues, with shipping limitations being an important early deciding factor. Current weight limitations for trucking delivery in the U.S. is 80,000 lbs., with some ability to go above this for overweight allowance. Unfortunately, the overweight limitations vary from State to State, but typically varies to a total of anywhere from 94,000 lbs. to 98,000 lbs. This leaves the purpose-built containers and 20' containers generally available to have most of the assemble and wiring work done at the manufacturing facility while 40' containers typically require some or all of the battery modules to be installed on-site due to shipping weight limitations.

The degree to which the enclosure can be delivered on-site fully integrated will significantly impact the amount of on-site work is required. The need to install some or all of the battery modules on-site can require upwards of 50% longer construction time than the pre-loaded container. However, larger enclosures do allow a denser placement of battery systems, so there can be a project benefit to utilizing the 40' containers.

Going forward there will continue to be a container vs. specialty enclosure debate. The answer to this will really be based on the question one is asking. If a high-density deployment is needed, then the 40' container should typically be chosen. However, if costs are a priority, it is proving out that the specialty-built enclosure is beginning to edge out the container cost in lower delivered costs up to a certain project deployment scale of roughly few 10's of MWhs. Very large systems of 100's of MWhs are still estimated to use container enclosures to be the most cost effective solution.

According to the U.S. Wood Makenzie/ESA Energy Storage Monitor (below) it is growing to a non-insignificant mid-single digit. This comes from the ability to manufacture at scale of a standardized battery enclosure and capture cheaper EPC costs. As fire issue continue to rise, specialty enclosures have an airgap to reduce fire propagation. Specialty enclosures also are easier to install, typically placed on a pad that can be easily replicated across the site. Both issues are important in reducing turnkey costs.

Turnkey balance-of-system costs of 2-hour-duration container vs. cabinet systems, 2019-2025E (\$/kW)



Figure 2-5. Container vs. Cabinet Cost Differential

Source: Q3 2020 U.S. Energy Storage Monitor

2.4.5. Thermal Management

Chemical batteries typically have an optimal range for operation; for instance, lithium-ion systems are designed to operate in the range of 20°C- 25°C. Normal operation of the cells will produce heat from the charging and discharging of the cell. A thermal management system is required to maintain that preferred temperature range. Without proper thermal management, overheating will lead to cells degradation, malfunction or even catching fire.

Properly sizing the Heating Ventilation and Air Conditioning (HVAC) equipment will result in better operating range and performance of the batteries, and a longer life. (HVAC and thermal management system are many times used interchangeably, even if the cooling system is not based on air handling.) Undersizing an HVAC system can easily lead to overheating which can lead to damage. Oversizing can also lead to problems, such as improper short cycling of the HVAC system during operation, which can also shorten that systems lifespan.

Excess heat will come from either the battery during operation, or the environment. Heat from the battery will be generated from normal operation, but high-rate activity will increase the heat generation rate significantly higher. Externally, heat will be generated from solar irradiation and the

ambient air temperature. If an air-based system, the humidity of the air will also impact the HVAC system's performance.

HVAC Systems are typically sized in Tons of Cooling required. One Ton of cooling is the amount of heat needed to melt 2,000 bls. of ice in a 24-hour period (equivalent to 12,000 BTU/hour.) Although estimates vary, it is not uncommon to oversize the cooling system by 50% in order to take into account added cooling loads and environmental conditions (although this could be higher if the system is exposed to more extreme conditions than warranted for a general rule calculation).

2.4.5.1. Technology Implications

Different energy storage technologies may require difference in HVAC capabilities. Even among Lithium technologies (LFP vs NMC) there can be a different operating temperature envelope as LFP is able to operate in a higher temperature range. Other technologies may require other changes; for instance, lead based systems may require explosion proof fans in the event of hydrogen production and ignition if over charged. Conversely, some technologies (e.g., liquid metal) require maintaining the batteries at an operating temperature of between 300°C and 350°C during operation. Allowing the cell to reach room temperature initiates a irreversible precipitate transition for some technologies, damaging the cell.

2.4.5.2. Cooling Medium

The cooling medium used in the HVAC system has significant implications as to the cost and performance of the energy storage system. Traditionally, air was used as the working medium, but liquid cooling is quickly becoming more widespread. The stationary energy storage market is able to benefit from the significantly larger effort being put towards the electric vehicle market, and the data center market.

Air based cooling system are typically less complicated and have a lower capital cost based on fewer components and have fewer modes of failure. Based on long-term use, the technology is highly reliable, and possesses the ability to be modified. These system work in battery systems by drawing out the heat from the modules either by blowing air through the racks or directed toward heatsinks. This is then either directly exhausted or can have a second loop with another heat sink on the outside of the system to ensure a sealed environment inside the enclosure.

Liquid cooling system utilize a dual loop design, with a glycol-based system typically acting as the working medium to remove heat from the batteries. Although designs vary, liquid cooling system typically can transfer 4X the heat of an air-based system of a similar mass. Therefore, liquid cooling systems generally take up less space than air-based system and are able to handle a larger surge of heat generation. On the downside, capital and maintenance costs are higher, there is the potential of leakage, and the units are typically heavier.

The decision to utilize an air based or liquid based system is sometimes based on cost, but increasingly based on a variety of performance issues. Air based systems cannot remove as much heat from the battery system as quickly as fluid based systems. This issue can be exacerbated in hot climates, where the inlet air temperature to cool the heat sinks are higher, reducing their cooling capability. Even assuming the two types of systems would be sized properly, liquid cooling retains the ability to remove more heat faster from the batteries, allowing them to operate in a wider dynamic range, and ensuring that the batteries stay in an optimal temperature range during operation to ensure compliance with the warranty. Finally, the transition to purpose-built containers has put a premium on interior spacing, giving a nod toward liquid cooled systems.

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3. OPERATIONS & MARKET STRATEGY: SYSTEM LEVEL

The system level of an energy storage system is a calculated balance between costs, capabilities, and market requirements. Some of these factors are relatively fixed, such as the capital cost of the equipment, but a surprisingly large amount of the costs is based on the operations of the unit. This can be technical issues such as O&M costs, round trip efficiencies, and thermal management. Other costs and concerns such as degradation and replenishment strategies are greatly impacted by the operation of the unit, but also incorporate a variety of external factors based on the market strategy followed by the owner/operator. Other issues are also heavily impacted by the market strategy of the deployed system, such as the energy management system used, and its capability to interact with local utilities, ISO's and financial markets when dealing with the sale of products and services.

3.1. Operations

There are a number of aspects of operations that are impacted by the unit's usage, and thus need to be taken into account for the design of an operating cost issues. The operation & maintenance (O&M) contract maintains the unit in a good working order and many times is required for warranty contracts. Round trip efficiency losses are based on the technology and usage pattern. Thermal management systems are important to mitigate external and internal sources of heat that can reduce the lifespan of the unit.

3.1.1. Operations & Maintenance

Operation & maintenance contracts are generally viewed as a fixed cost as the contract is not directly based on the day-to-day operation of the unit. They remain critical as availability and good performance of the unit is essential to generate revenue.

These contracts contain both aspects of remote monitoring and on-site visual inspections. Major cost drivers are the frequency of on-site inspections and the amount of replacement of consumable parts (filters, fans, etc.) plus other parts for preventative maintenance. The inspections will cover the battery system, HVAC, and power electronics. Remote monitoring in particular helps lower the cost to inspect the units. It also provides an opportunity to gather data for predictive maintenance, as the body of operating experience grows. Operation and maintenance concerns have grown with the push toward longer-lived systems, driving a focus on the operation of the facility over time, rather than maintenance of the initially installed equipment and hopes that it will operate whole life without incident.

Another driver in cost variation is the type of energy storage technology. Chemical batteries such as Lithium-ion systems are typically a low-maintenance cost technology as compared to others with moving parts that require more frequent maintenance. On average, higher usage of the system will require more maintenance for all technologies. In addition, those technologies without significant field operating experience will have more of an open question as the O&M needs to maintain expected performance levels for a wide variety of applications—especially when operating in multiple modes simultaneously.

Typical maintenance costs are contracted for a specific annual dollar value per year, although the range can vary widely depending on the level of reliability desired. These costs correspond to a range of anywhere from 1% of the capital cost, to 5% per year. This has generally cover one or two visits per year to visually inspect the system and change out consumables such as air filters for the cooling systems.

In order to reduce downtime from failed components, preventive maintenance efforts have become an important aspect of maintenance contracts. These programs rely on both remote monitoring data and visual inspections, typically annual, but can occur with more frequency if warranted. Key areas of inspection and testing include the battery system (power and energy capacity, RTE, sensors and cabling), balance of system (enclosure, fire suppression, HVAC) power conversion system (inverter, switchgear) and energy management system / communication.

3.1.2. Round Trip Efficiency Losses

Round trip efficiency (RTE) losses represents a key variable operating cost for energy storage facilities and can lead to significant negative economic impact—especially for more actively usage profiles. As one would imagine, different energy storage technologies have different round trip efficiencies based on the method needed to convert the electrical energy into a form for storage, and back again. These charging costs will also vary between technologies as the round-trip efficiencies vary widely—flow batteries can achieve into the 80% range for round-trip-efficiency (DC:DC), whereas lithium-ion modules routinely state 95%+ round trip efficiency (DC:DC).

Monthly round-trip efficiency, by storage technology (Jan 2018–Dec 2019)

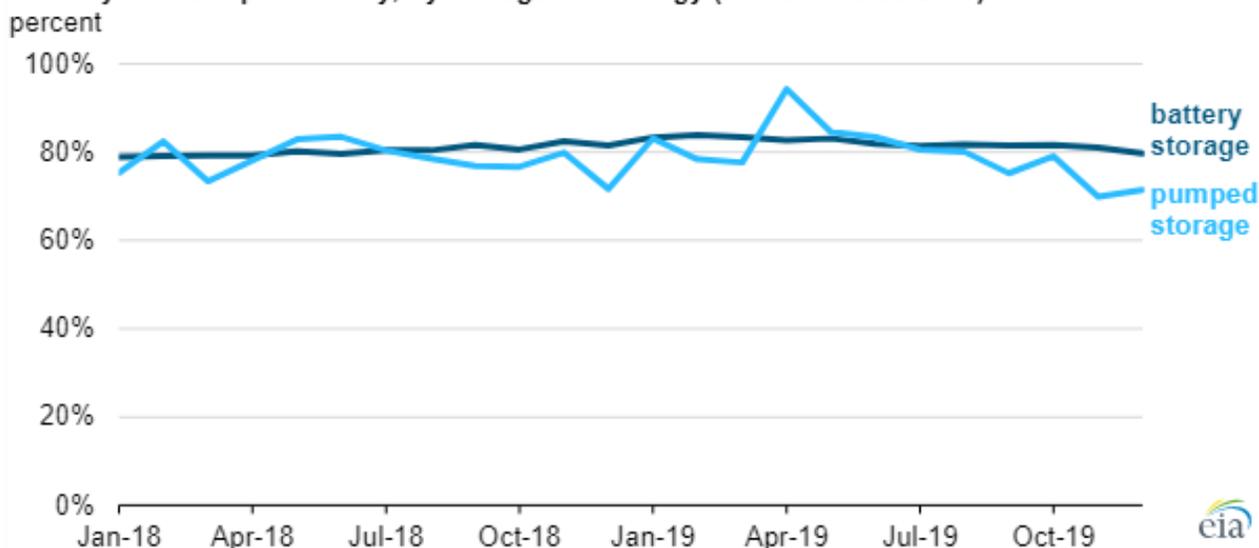


Figure 3-1. Round Trip Efficiency by Technology

Source: U.S. Energy Information Agency

In reality, average AC level RTE values based on real-world experience are lower than the optimal values provided by manufacturers; for instance, lithium-ion systems are typically found to have an 80% to 85% RTE. Beyond the losses from resistance in the cells, auxiliary load such as the on-board controls (generally minor) and HVAC (possibly significant) should be included. The load from the HVAC system will be driven both by environmental loading (possibly desert environment) and usage profile, so although any estimation of the “normal” HVAC load can be provided by the OEM, an actual calculation should be done for the specific facility under intended conditions and usage profile.

3.1.3. Thermal Management

Incorporating a well-designed thermal management system is a critical component for the successful long-term operation of the energy storage facility as power density and usage increase⁸. Lithium-ion systems are generally designed to operate at 20°C (68°F) to 25°C (77°F). Charging and discharging the system (especially for longer periods and at higher rates) produces heat from the conversion process. Operating at significantly below or above the designed temperature will have negative impacts on the efficiency of the charging and discharging, as well as shortening the lifespan of the batteries. Thermal management also important to manage the external temperature impacts from harsh environments, be they either desert or arctic conditions. Maintaining the system at these temperatures is also becoming an important component of warranty coverage.

There are typically four areas of thermal management that are important, the first three dealing with cooling, and the fourth with heating. These are

- 1) Source of Heat,
- 2) Removing the Heat,
- 3) Targeting the Heat Removal, and
- 4) Heating the system.

3.1.3.1. Source of Heat

Batteries are not 100% efficient when charging and discharging; the power that does not get transferred through the battery is predominately converted into heat. This conversion does not happen evenly throughout the operation of the charge/discharge cycle. The heat generation is generally flat between 20% SOC and 80% SOC. Below 20% SOC, resistance in discharging decreases efficiency and creates heat, while above 80% SOC resistance in charging decreases efficiency and creates heat. Charging efficiency drops significantly on charging near 100% SOC as energy is lost through the balancing operation.

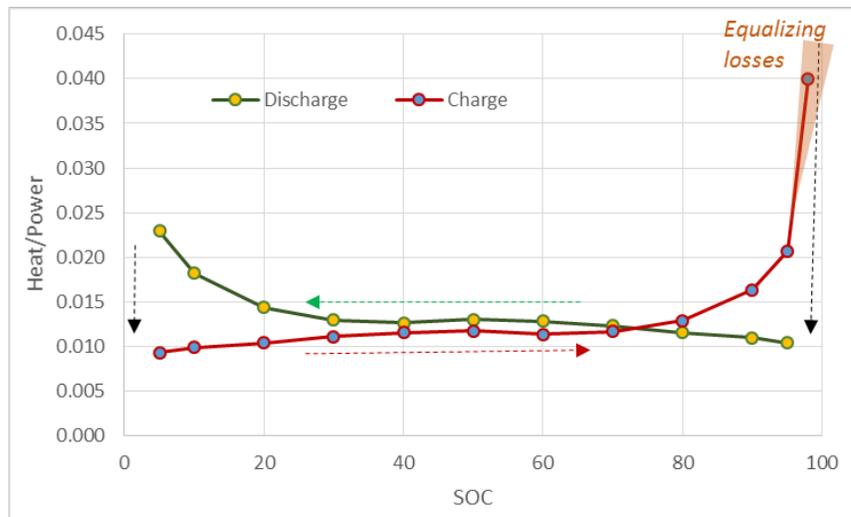


Figure 3-2. Charge / Discharge Efficiency

Source: The importance of thermal management of stationary lithium-ion energy storage enclosures

The conditions where the batteries are placed are also important. For instance, if the location of the battery facility is in a hot environment/desert, then any air conditioner would work poorly as the inlet air temperature would be high; in extreme situations, this can reduce the capabilities of the HVAC system. For this reason, HVAC system are typically sized larger than what is the design requirement. This becomes of greater importance if maintaining the batteries in a particular temperature range is a condition of the warranty.

3.1.3.2. Removing the Heat

In order to remove the heat from the operation of the energy storage system, the unit needs to be sized properly to handle to expected cooling requirement. This calculation needs to take into account the total heat produced from operation over is intended usage profile, but also the rate of heat production, which can vary significantly based on operation. The following table showcases the impact of different rated of operation on cooling requirements.

Battery System	Power Rating	kW	250	500	1000	2000	4000
	C-Rate		1/4	1/2	1	2	4
	Discharge Time	Hr	4	2	1	0.5	0.25

Heat Source	Batteries		2.2 kW	8.8 kW	35 kW	140 kW	560 kW
	Bus System		0.1 kW	0.4 kW	1.8 kW	7 kW	28 kW
	Auxiliaries		1 kW				
	Environment		1.5 kW				

Total Heat	4.8 kW	12 kW	40 kW	150 kW	593 kW
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Figure 3-3. Heat Load for a 1-MWh Enclosure

Source: Sabre Industries

Most current thermal management systems are designed around air handling systems, but the increasing prevalence of liquid cooling systems in vehicles (and data center environments) are beginning to transition their use in the stationary energy storage market. These liquid cooling units offer the ability of greater heat transfer capacity, save space, and can provide more targeted cooling. Liquid cooling also has an advantage when operating in a hot environment, as the cooling capacity of the system becomes derated due to the high inlet air temperature.

3.1.3.3. Targeting the Heat Removal

As the industry matures, enclosure design is optimizing towards a more dense-pack design in order to allow for maximum deployment density. Rack design in the enclosure is also trending towards higher battery density in order to reduce wasted space. Both of these trends are reinforcing the migration from air to liquid cooling as is it becoming more difficult to get sufficient air through the system to cool the unit sufficiently, especially in the interior of the battery rack.

These issues are requiring that OEMs take the usage patterns of customers into account when designing systems, and becomes more important with constant use. This is important as the OEMs could possibly reduce the usage capability of the unit below what is possible if the system can n be cooled properly during operation to maintain the unit at the temperature range referenced in the warranty operating limitations.

3.1.3.4. Heating

Lastly, some energy storage technologies require a heating source to maintain the core battery technology at elevated temperatures. These systems are typically a molten metal battery, such as the sodium sulfur technology. Generally, these technologies obtain sufficient heat from normal operation of the unit to maintain the required temperature. However, molten storage technologies can many times suffer irreversible phase change damage if the unit is allowed to cool to ambient temperature, so these systems will incorporate a separate back up heat generator in the event the system is taken off-line for extended periods of time.

3.2. Degradation

An important aspect of energy storage technology is that the energy storage rating (kWh) can decline over its lifespan. This will vary by technology and can have a material impact on the financial viability of the facility's offtake agreement. For that reason, understanding the reduction in the unit's capacity rating and the strategies to counter it are of a first order importance to the owner/operator.

Degradation is the reduction in the energy rating capacity (kWh) of the battery's energy storage capacity over set period of time. Therefore, over the life of the system, how much energy can be cycled through will decline (keeping the number of cycles the same). Different energy storage technologies will experience degradation at different rates, with some technologies showing little or no degradation while others experience significantly more. The amount and rate of degradation change is generally based on the technology; those relying on electrostatic, mechanical, or purely reversible chemical reaction will experience little or no degradation during the transformation of the electrical energy. However, this is not true of all chemical storage systems; flow batteries are generally designed for limited to no degradation of energy storage capacity during operation. Cell-based chemical energy systems—batteries—do undergo physical change, and thus degrade during operation, thereby losing some portion of initial battery capacity over their operating life.

Degradation comes through two general pathways: calendar aging and cycle life. Calendar aging accounts for the eventual capacity loss resulting from the slow chemical changes to the battery material and interfaces, reducing or eliminating its reactivity for the reversible storage process. The cycle life aging of the battery is driven by operational factors and also impact the active battery material. Both are impacted by environmental temperature, operating range for the state of charge, charging/discharging rate, etc. The amount of decline will depend on under what conditions the battery is stored, and how the battery is used; depending on these factors, the degradation rate will be faster or slower.

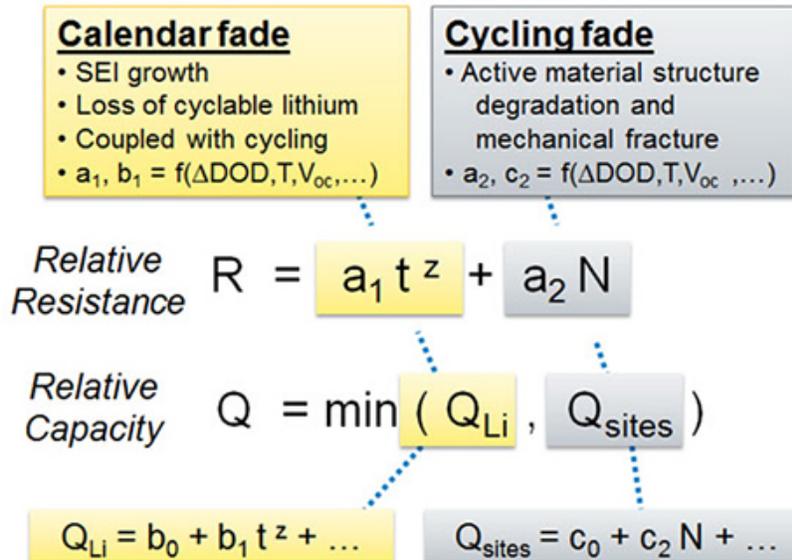


Figure 3-4. Energy Storage Degradation

Source: NREL

OEMs provide degradation schedules to detail the expected lifespan of the battery. Since there are a number of issues that impact this (external and internal), these generally take form a estimated lifespan, based on a series of environmental and operational assumptions. If conditions fall outside of these estimates, adjustment factors are provided to estimate the resulting new degradation schedule.

A battery’s degradation schedule is a fundamental component of an OEMs warranty. Each technology will have a different schedule, and even within the same technology (lithium-ion LFP or Lithium-ion NMC) OEMs will have different schedules based on their own design and manufacturing, quality, and capability.

For this reason, it is imperative for system integrators and project developers to have a deep understanding of the degradation factors so they will understand the operational capability and flexibility of the system overall. They need to design the overall system that balances the design capabilities and usage profiles, the result which then bears directly on the replenishment costs (next section) to maintain a particular energy storage rating of the system over its lifespan at the most cost-effective pathway.

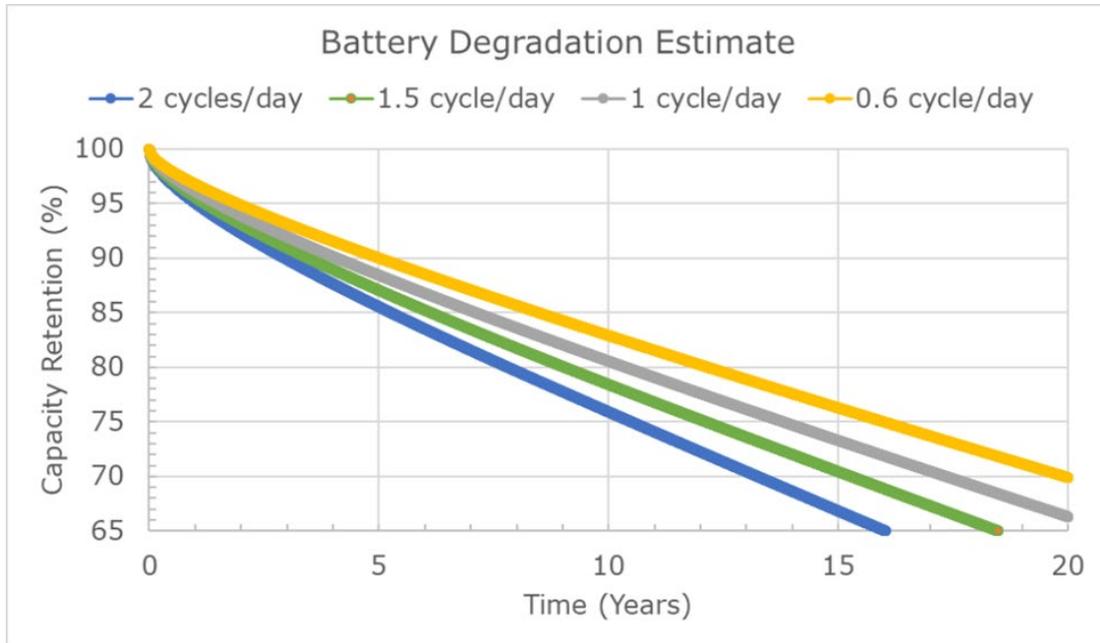


Figure 3-5. Lithium-Ion Battery Degradation

Source: DNVGL

3.3. Replenishment

It is critical that project developers incorporate a strategy into the life-cycle plan of the project in order to ensure that the facility will be able to maintain sufficient capacity (kWh) over its lifetime to meet any contract obligations or market strategy requirements. This strategy is increasingly referred to as a replenishment strategy—a plan that takes into account the needs to replenish the battery capacity of the facility as required.

This replenishment strategy is dependent upon several factors that will affect the degradation of the energy storage technology’s capability, including the type of energy storage technology, the expected usage profile, and the environmental conditions where it will operate. It should be noted that a number of technologies do not have significant degradation in the energy capacity of the system over their lifespan, and thus do not require this added cost to support the project outside of the standard maintenance efforts. The rest of this section will deal with technologies that experience degradation like lithium ion or lead.

Replenishment strategies attempt to find the least-cost approach to obtain the required capability of the system over its lifespan. The challenge is to map the declining capability of the batteries with the expected usage profile over time to determine how much additional storage capacity must be added. Since the energy rating of a cell-based battery system is expected to decline over time, installing only that which is needed now incurs the least cost for the batteries, but incurs other balance of system costs.

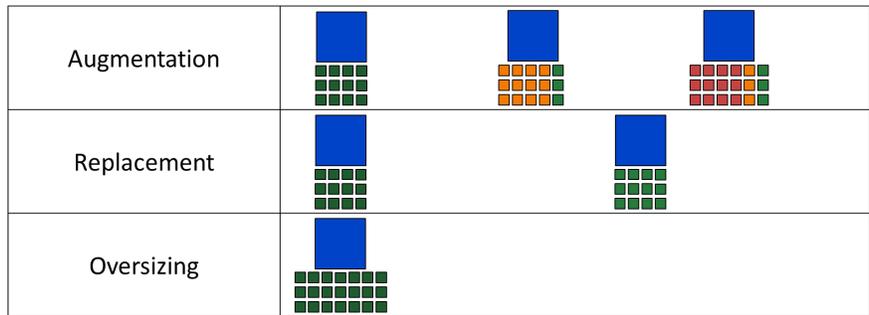


Figure 3-6. Energy Storage Replenishment Strategies

Source: EPRI

A key point underlying this effort is the technical operating lifespan of the storage asset. Most chemical batteries have a gradual and roughly linear decline in capacity over its lifespan until it reaches a point where the degradation per cycle accelerates. This point has typically been the “technical lifespan” of the cell, historically when the cell has 80% of its capacity remaining. This point has historically been called the “knee.” Advances in battery technology and significantly greater operating experience has extended the roughly linear declining lifespan of cells until the 75% or 70% remaining capacity is reached.

Due to the declining cost of the battery modules, the typical cost minimization strategy is to only incorporate only enough capacity to ensure compliance with the required amount. This strategy thus pushes off into the future as much of the replenishment as possible as future batteries are expected to cost less. Determining the least-cost replenishment schedule will continue to vex many project developers who desire to use the energy storage facility for a number of applications.

Three strategies are prominent in most replenishment plans, initial oversizing of the facility, periodic augmentation of the battery capacity, or replacement of the initial capacity. An overall replenishment strategy can incorporate one or more of these individual strategies. The typically strategy is some mixture of initial oversizing—with augmentation occurring a few years into the future. If the facility is designed to have a significantly long life with constant use, a replacement is sometimes called for. All of these milestones are in flux as battery performance continues to improve.

3.3.1. Oversize

Initially oversizing the energy battery capacity is a common strategy for many project replenishment strategies. This produces a system that has additional capacity early in the operating life of the unit as many batteries can have a faster first year degradation, or in the event of an unplanned capacity reduction in the early part of the operating life.

Initial oversizing also comes into play when contemplating the planned lifespan of the unit. This typically can range from 10% to 33% of the rated energy capacity. For small systems with a 10-year lifespan, initial oversizing is generally sufficient to support most planned usage patterns. For longer lived systems, the initial oversizing will give the operator actual degradation experience that can be used to calculate a later augmentation or replacement.

3.3.2. Periodic Augmentation

Periodic augmentation represents the intermittent addition of battery systems over the facility’s operating lifespan needed for the system to maintain the capability agreed to under the performance

guarantee or support a specific usage profile. The augmentation strategy benefits from the expected lower cost of energy storage systems in the future.

A key component of the forward deployment cost is the required additional balance of systems and EPC costs. Early augmentation strategies relied on adding additional fresh modules to existing racks, but this created a situation with differently aged battery modules which lead to premature aging due to balance activity. Common practice now is to plan for this at the beginning of the project by building out additional spacing for new racks or entire enclosure deployment sites and electrical connection points during the initial build-out.

3.3.3. Replacement

The third strategy is replacement of the existing storage modules if their technical operating life does not last as long as the project's operating lifespan. Like the augmentation strategy, this strategy will benefit from a lower future cost of batteries, lowering the effective replenishment cost.

A critical deciding point for this strategy is the warranty coverage of the battery system. Since many lenders require all of the equipment to stay under warranty during the loan period, modules that reach the end of warranty coverage will be replaced for contractual, rather than a purely technical choice.

3.4. Energy Management Software (EMS)

As energy storage systems become more versatile and interconnected with external management systems the control suite of energy management systems is becoming more important. The EMS monitors and manages the real-time operation of the energy storage asset, and is used as the basis for optimizing the performance of the system.

3.4.1. Components

Energy management software is critical achieving a successful energy storage system operation. Typically, there are three components of the energy management software: Market Analytics, Site Controller and Management, and Communication and Portfolio Management. It should be noted, however, that not all software suites have all of these components, due in large part typically to the market focus of the provider.

3.4.1.1. Market Analytics

The market analytics layer provides decision intelligence and critical insights into the physical and economic conditions where the energy storage asset(s) operate. This entire modeling component can quickly become complicated forecasting market prices and strategies in a dynamic environment. Here, data feeds from the software provider's central hub are evaluated to discern what would be the most profitable and valuable operation in both the short term and long term. This may be one of the most specific and complicated differences between energy storage and other power sector market analytics. Due the inherent limitation of storage capacity and lifespan of the energy storage system, there is always a feedback loop between market strategy, and lifespan/capability of the unit.

3.4.1.2. Site Controller & Management

The local site control and management layer monitors and manages the energy storage asset at a specific site. The site controller first serves as a single collection point for the performance data of an energy storage asset. The unit gathers critical status on equipment and performance data of

battery and auxiliary components for diagnostic and control. The site controller also handles the controls and coordination of energy storage system dispatch. The site controller can either make autonomous decisions using pre-selected strategy or incorporate user selected input. For both avenues, the site controller will generally be able to provide an optimized performance strategy weighing the short-term economic gain with long-term health and limitations of the batteries, and auxiliary equipment (inverters and HVAC equipment).

3.4.1.3. Communication and Portfolio Management

The Communication and Portfolio Management layer provides the ability to coordinate one or more independent units for remote monitoring and coordinated market operation. Increasingly, this is including both energy storage and other DER technologies. This Portfolio Management can then communicate with either utility distribution management systems for remote control, or to a trading desk for bidding purposes into an ISO/RTO clearing market for services.

3.4.2. Applications

Energy Management Systems are designed to control the operation of one or more energy storage assets to provide a desired set of market applications. Based on a library of application-based algorithms and embedded neural based learning capabilities, the typical EMS is able to independently manage the operation of an energy storage asset, improve its operation based on experience with the asset in changing market conditions, but also incorporate user designated directives as to the desired outcome. In support of this higher-level goal targeting is an internal balancing of operations requested versus the long-term management of the system. The level and sophistication of the programming of the EMS will vary from provider to provider and will have a direct bearing on the type of applications that can be supported. As the operating environment becomes more complex, the need to manage the co-optimization of multiple value streams concurrently gains in importance.

The operational mode of the EMS local site controller is generally tied to its market function, either Front of the Meter (FTM) or Behind the Meter (BTM) operation. Fleet management responsibilities of combining multiple sites adds additional complexity as the need exists to maintain the assets performing the operation / bidding into the market conform to the limitations and requirements of the utility of ISO/RTO.

Typical applications provided include:

- **Front of the Meter (FTM):** Key among the wholesale market applications provided include ancillary services (for both ISO/RTO markets and utilities) such as frequency regulation, spinning and non-spinning reserves, reserve capacity, energy arbitrage, ramping support, and black start. Off-take revenue contracts for these services will typically be governed by the market environment where the energy storage asset operates, including either the ISO/RTO services market or bilateral contracts with individual utilities or customers.
- **Renewable Assets:** Typically incorporated into a design that provides a hybrid renewable/storage asset. The energy storage component is designed to improve the capability and value of the renewable generation through firming capacity, voltage support, providing time-shifting of production, and maintaining production to the grid within a pre-defined dead-band to improve reliability and integration into the larger power market.

- **Behind the Meter (BTM):** Many energy storage EMS system are designed to manage on-site energy storage assets and provide better reliability and economic benefit for the customer. Many of the energy management systems are designed to not just manage energy storage assets, but distributed energy resources (DER) in general, vastly improving the EMS capability and value to the customer. Key applications for this market include peak shaving, energy time shift, electric vehicle charging, onsite PV/Wind production, and reserve power/reliability.
- **Microgrid:** Incorporating many of the functions in the other market capabilities, some energy management systems have been designed to manage all local assets in order to match the local load. The complexity of this function will depend on a number of issues, such as whether the microgrid has a connection to the larger local utility grid, or is designed to operate independently, the nature and scale of local generation, the amount of energy storage assets, and the scale and variability of the local load requirements.

3.4.3. *Enel X*

Enel X's DER Optimization Software⁹ (DER.OS) is a scalable management software system designed to monitor and manage Behind the Meter (BTM) distributed energy resource to maximize its economic value. The software is scalable, allowing for the management of a single 100kW system, or aggregation of multiple assets into the MW range. DER.OS allows customers to manage demand charges and avoid high time-base electricity costs, while also supporting their enrollment into utility demand response programs, as well as other utility-controlled capacity programs. The seamless integration of a variety of DER assets is a critical strength of the DER.OS. By combining both onsite energy production, energy storage, and demand response enrollment, the DER.OS is able to provide greater grid stability with enhanced customer reliability.

The core of the DER.OS is the local site controller. This software provides control for a variety of DER Resources, and supports a number of insights, including advanced site awareness, demand profiles, weather impacts, and time of use charges. The DER.OS Site Controller is based on a battery agnostic architecture which allows for seamless integration of lithium, flow battery, or other battery chemistries. The DER.OS monitors and tracks asset performance in real time, allowing the customer to directly select or utilize predefined operational strategies in response to load fluctuation. Coupled with this input, the DER.OS then determines the optimal battery operational strategy to maximize value from the different revenue streams, tariffs, and incentives. The software is able to integrate with customer's existing building management software, PV system, and EV charging systems. Through this integration, the DER.OS software is able to support a number of applications, including peak shaving, energy time shifting, renewables integration, EV charging, voltage/frequency support, critical load support and back-up, and microgrid operations.

The DER.OS optimization software also contains a cloud-based component to manage external interaction. This layer provides market intelligence and a management control for utility tariffs, electricity prices, and demand response market in order to affect the most economic management of the DER equipment under management by the DER.OS. This interface can be tailored to a variety of external systems, including utility DMS, building management systems, renewable energy control. The DER.OS supports a variety of user interfaces, providing for real-time review of performance and current revenue generation, as well as the ability to review historical operational and market conditions. Utilizing the cloud-base component, customers are able to monitor, manage, and coordinate multiple sites into a single energy strategy.

The DER.OS optimization software is able to support a variety of applications, including:

- **Bill Savings/Tariff Management:** Minimize the overall system cost and maximize the system's economic value. Through an optimal BESS discharge and charge strategy taking into account demand, weather, and market data.
- **Grid Revenue Generation:** enables storage systems to capture revenue from many different grid products and ancillary services. This can be enabled through automatic dispatch but can also be controlled through manual dispatch.
- **Financial Reporting:** Provides 5-minute interval bill savings based on BESS operation, PV production, and tariff data.
- **Monitoring & Asset Management:** Monitor and manage system status and operating parameters.
- **PV Monitoring:** Provides basic solar monitoring and reporting of PV production data.
- **Alerts:** Provide alerts for abnormal changes in data collection, system operation, or changes in savings.
- **Data Accessibility:** Ensures data collected by the Enel X site controller is available locally, as well as stored remotely in the cloud for long-term storage.

3.4.4. Fluence

Fluence provides clients of its energy storage systems software suite to understand emerging market opportunities and coordinate the operation of their assets to exploit them for the greatest economic gain. The fully integrated software suite combines market intelligence with asset and fleet control that can be coupled with Fluence's proprietary energy storage hardware to improve asset performance at a single site or across entire fleets. The software suite¹⁰ is comprised of three components: Fluence IQ, Fluence Operating System and the AMS Trading Platform.

Components of the Fluence software suite include:

- **Fluence IQ:** The Fluence IQ software package provides intelligent decision-making support and optimization for a single energy storage facility, or a fleet. This allows owners and operators to enhance performance and lower operating costs. Fluence IQ is able to manage a wide range of operational parameters, including monitoring system status, unit availability, round trip efficiency, and state of charge. The system is also able to monitor the battery state of health and manage battery degradation to stay within off-take contract requirements and warranty limitations.
- **Fluence Operating System (OS):** The Fluence Operating System (OS) software package provides monitoring, management, and site control for an energy storage facility. It provides visibility and down to individual components, allowing it to provide control for the facility to improve system efficiency and effectiveness. This level of control can be extended from a single facility to an entire fleet.
- **AMS Trading Platform:** The AMS Trading Platform supports energy storage systems by improving the facility's ability to increase revenue with a reduced risk profile through improved and more intelligent operation within existing equipment limitations or impacting warranty constraints. The AMS Trading Platform optimizes bidding based on proprietary

prices, supply, and demand. It develops a revenue-maximizing bid strategy, incorporating parameters and limitations of regional market for including energy, ancillary services, and offtake contracts. Finally, the system can optimize the bidding strategy of a single facility or a fleet of assets (including storage, hybrid, renewable, etc.) to achieve predetermined objectives.

3.4.5. Fractal Energy Storage Consultants

Fractal Energy Storage Consultants provides Fractal EMS¹¹ to customers as an independent EMS software provider. According to the firm, Fractal EMS is an integrated system that provides full command, control, monitoring and management functionality for a single energy storage asset or a fleet or assets location anywhere in the world.

Components of the Fluence software suite include:

Site Controller: The Fractal EMS provides provide owners and operators with real-time monitoring and diagnostic capabilities for the onsite unit, including monitoring of the health and operational performance metrics at the system and rack level. Advanced analysis capabilities help to identify irregularities in operation, areas of concern, and proactively detect operational issues. The Fractal EMS allows owners and operators to operate the battery and auxiliary equipment and schedule operations and unit dispatch. Some of these operation capabilities include:

- **Module BMS Level:** Collects and records module level battery information, voltage and temperature status.
- **Bank BMS Level:** Collects information from the battery racks to report status and diagnostic capabilities.
- **Rack BMS Level:** Provides module control and data aggregation at the rack level, allowing the reporting of cell balancing, energy levels, power levels, voltage, temperature and contactors status.
- **System Level:** Manage battery operations and provide reactive power from inverters.
- **Unit Controller:** Aggregates information from the inverter, BMS, thermal management and fire suppression.
- **Auxiliary Level:** Manages thermal management system to optimize performance and maintain warranty compliance, and provides status, alerts, and automatic activation of fire suppression to ensure system safety.

Remote & Fleet Management: The Fractal EMS provides owners and operators the ability to monitor and manage a distributed fleet of energy storage assets. This level of monitoring, system integration, automatic and active management provides for a variety of control strategies to maximize economic value of the assets. The system is scalable, allowing for a large portfolio to be constructed across a wide range of markets, dispatching single installations or the entire portfolio, based on strategy.

The Fractal EMS is able to support a variety of applications, either at a single site or across the portfolio. Based on the software's advance algorithms, the Fractal EMS is able to develop the most valuable application stack utilizing proprietary optimization dispatcher that takes into account both market pricing, contract requirements (economic and dispatchable) and system life to optimize overall performance.

3.4.6. **GE Renewable Energy**

GE Renewable Energy provides the capability to better monitor and manage hybrid power plant operations. Hybrid power plants operate under different conditions and limitations than either standalone solar or energy storage system by themselves. FLEXIQ¹² is built on the capability to manage these assets both independently and together, providing a unified and dynamic control & software platform to enable optimized system performance.

Components of the GE Renewable Energy's FLEXIQ include:

- **Hybrid Architect:** GE Renewable Energy's Hybrid Architect supports the design phase of the project development by optimize plant configuration from a variety of inputs through economic evaluation to maximize project value. This tool is specially designed to evaluate the economics of hybrid renewable power plants, highlighting the economic impact of technical design choices. Capabilities include simulating plant operation, improving plant design, evaluating project lifecycle costs, and calculating different revenue streams.
- **Plant Control:** GE Renewable Energy's Plant Controller coordinated single or multi-installations of power facilities, managing the active and reactive power flows. This component can be integrated into standalone energy storage, solar, and hybrid facilities. The Plant Controller monitors and optimizes the operation of the plants in the portfolio. Capabilities include managing application co-optimization, active power response, supervisory control functions, real-time and historical analysis, and cyber security.
- **Dispatcher:** GE Renewable Energy's Dispatcher maximizes unit economics through optimizing the energy storage charging and discharging schedule. This schedule is sent to the Plant Controller in real time, although the schedule can be updated as conditions change. Capabilities include dynamic scheduling and market forecasting.
- **Monitoring & Diagnostics:** GE Renewable Energy's Monitoring & Diagnostic's component monitors the performance of individual or multiple assets of a portfolio and provides a modeling framework for forecasts and analysis. This capability is done in real-time and allows a more centralized management of the fleet of assets in a particular portfolio. Capabilities include energy storage system health, unit status visibility and predictive analysis.

3.4.7. **Indie Energy**

Indie Energy provides the Indie EMS¹³ to manage energy storage and renewable energy assets. The software suite provides owners and operators insights into the state and performance of an energy storage system.

Components of the Indie Energy EMS software suite include:

- **Local Site Controller:** The local site controller provides owners and operators real time monitoring and control of the facility. The capabilities include rigorous monitoring capabilities in order to monitor and manage battery life management, conduct real time cycle cost benefit analysis, and ensure equipment warranty protection. With these insights, the Indie EMS is able to provide a suite of control functions to operate the facility in a number of market applications, and to provide islanding and backup power support for a local load. The Indie EMS is able to be integrated into a variety of assets, including energy storage, solar, wind, and customer loads.

- **Indie Fleet Controller:** The Indie Fleet Controller is able to monitor and manage a number of Indie EMS Local Site Controllers. By integrating the dataflow from the different installations, the Indie Fleet Controller can apply a suite of System Analytics and control functions to provide alerts and notifications for the various remote facilities. The software can use the data and analysis for in-depth performance monitoring and warranty protection for the entire fleet. By aggregating all of the data and analysis from the asset fleet, the Indie Fleet Controller can provide a centralized and secure data storage library.

The Indie Fleet Controller is also able to import market data and weather forecasts to develop detailed load forecasts for all facilities. This provides the capability for aggregated bidding by all coordinated assets as a virtual power plant (VPP).

3.4.8. Powin Energy

Powin Energy incorporates their proprietary StackOS¹⁴ energy management system software with their battery hardware to ensure unparalleled operational capabilities for customers. StackOS provides deep transparency into the operations and health of the battery stacks, originating from cell level data. By monitoring the battery operations at this level, its capability allows to owner and operator to dispatch the battery systems according to a number of predetermined algorithms. StackOS allows the owners and operators to remotely monitor and manager all component of the energy storage system, including the battery stacks, PCS, HVAC, and fire suppression system.

Layers of the Powin Energy Stack OS include:

- **Battery Management and Safety:** Powin Energy’s proprietary StackOS BMS provides industry-leading active balancing and cell-level monitoring capability. The layer also provides best-in class safety functionality for owners and operators.
- **Total System Integration & Control:** Powin Energy’s proprietary StackOS provides owners and operators full control of the energy storage system, including, the PCS, HVAC, Fire Suppression, and Stacks, down to the cell level.

3.4.9. Tesla

Tesla’s provides an integrated software suites under the Tesla Energy Software¹⁵ umbrella to manage the operations of its energy storage systems and maximize the value of the facility. The software suite is scalable, able to support all levels of Tesla battery systems, ranging from the small behind the meter Powerwall unit to the commercial and utility scale Powerpack and Megapack systems that can reach 100MW or more. The software is also able to control single or multiple systems deployed in different locations.

- Components of the Tesla Energy Software suite include:
- **Powerhub:** Powerhub is a monitoring and control platform for managing power industry assets, including distributed energy resources, renewable power plants and microgrids. Powerhub provides the capability of a Supervisory Control and Data Acquisition (SCADA) system.
- **Microgrid Controller:** Microgrid Controller is able to provide grid stability and reduced operating costs in a microgrid environment. By controlling all power components in the microgrid (utilizing Powerhub), Microgrid Controller provides real-time control and site optimization for isolated microgrids, or ones integrated with a local power grid.

- **Autobidder:** Autobidder allows owners and operators better ways to monetize their battery assets. Autobidder is a real-time trading and control platform that allows owners and operators to develop flexible operational strategies to maximize revenue under a number of operating strategies and risk parameters. The software can be configured to support a number of market applications for energy storage systems. The core analytical module can then manage an optimized value-stacking operation as it takes into account changing market conditions. The system will take into account and optimize a number of user preferences, including revenues, warranties, and maintenance agreements. Because Tesla provides an integrated software and hardware offering, owners and operators can be assured that energy storage warranties are protected under Autobidder management.
- **Opticaster:** Opticaster is designed to maximize economic benefits and optimizes operation according to a number of strategy parameters. Some of these include cost reduction, maximizing renewable energy production, and optimizing exporting renewable power during peak load periods.
- The software suite was designed to support a variety of market roles. In the wholesale market, the system can support including energy and capacity products, ancillary services, transmission and distribution services, renewable firming and shaping, and bilateral contract arrangements. Tesla also supports customers with a network operating center to monitor facilities 24/7.

3.4.10. Wärtsilä

Wärtsilä provides the GEMS energy management platform¹⁶ to monitor, control, and optimize energy project facilities including storage, renewable, and thermal generation (hybrid). The GEMS software is designed to give operators a deep view into the system operation, allowing them to optimize the system performance, reduce costs and provide proactive warranty protection through limiting excessive operation when needed. Through its machine learning capability, the software can adapt and learn from market changes while operating under safety and warranty limitations.

GEMS contains four components that support different aspects of asset management.

- **GEMS IntelliBidder:** GEMS IntelliBidder supports smart bidding based on forecasted data and history analysis. The GEMS Rule Engine allows for the system to alter operations base on a variety of market and environmental conditions.
- **GEMS Power Plant Controller:** The GEMS Power Plant Controller (PPC) monitors, manages and optimizes single site power facility installations of all sizes.
- **GEMS Grid Controller:** The GEMS Grid Controller (GC) is designed to optimize and manage a microgrid environment, utilizing intelligent grid control and optimizing power management.
- **GEMS Fleet Director:** The GEMS Fleet Director (FD) provides a centralized visibility into and command for a fleet of power facilities, allowing for secure monitoring and control of equipment status and supports analysis of operation history. This component integrates with the GEMS PPC.

The GEMS software provides a unique capability for energy storage facilities. This is based on a long history of managing energy storage assets in a variety of deployments and applications. GEMS was designed to be technology neutral and has been integrated with 16 different batteries and 12

power conversion systems. The software supports multiple value streams for energy storage system operation, including frequency regulation, spinning reserves, and VAR support while optimizing an efficient O&M schedule for the facility.

3.5. Communication

In order to coordinate the activity of the energy storage asset with a utility management system, the energy storage facility must incorporate a communication system that adheres to the growing body of standardized communication protocols, but also maintains the unit securely from cyberattacks.

3.5.1. SCADA

Supervisory control and data acquisition (SCADA) systems are a standardized method of monitoring, measuring, and managing a variety of distributed individual electrical components. Utilities utilize SCADA systems extensively to monitor and coordinate the capabilities of all of the different components of the distribution network in order to provide service to their customers.

Initially deployed at the higher voltage transmission system, they have been deployed increasingly down into the lower voltage distribution system, especially as more and more utility assets are distributed throughout the power grid. Utilities are also utilizing SCADA systems to directly control BTM energy storage assets as part of a utility capacity or reliability program. Some commercial and industrial energy storage components are set to be controlled by the Utility Distribution Management System.

3.5.2. Distributed Energy Resources (DER)

With the increasing scale of DER assets, as well as their growing sophistication and capability, standardization of communication requirements has been a critical issue to ensure energy storage assets are able to be utilized in as many deployments as possible. The importance of this is evident by the release of IEEE 1547-2018 - *IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*¹⁷ which contained requirements for improved standardization of communication interfaces for all DER equipment.¹⁸

Some States like California have extended the reach of standardized DER communication equipment. The California Public Utility Commission has mandated that all new DER equipment include communications pathways to the three California Investor-Owned Utilities (IOUs) in Electric Rule 21, with other states evaluating the option to develop their own.¹⁹

3.5.3. Cybersecurity

With the increasing level of connectivity of energy storage systems, cybersecurity is a growing concern for operators. Cybersecurity represents the protection of the management and control systems from digital attack. The cyberattacks will vary, but they are typically aimed at accessing the control systems to either gain access to sensitive data or interrupt the operation of the unit.

The National Institute of Standards (NIST) has developed a Cybersecurity Framework²⁰ around the five functions of Identify, Protect, Detect, Respond, and Recover. While this document was developed to improve cybersecurity risk management in critical infrastructure. The Framework enables organizations to apply the principles and best practices of risk management to improving security and resilience.

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4. OPERATIONS & MARKET STRATEGY: PROJECT LEVEL

A successful energy storage project design leverages the capital equipment in the most cost-effective market operation strategy available. This is easier than it sounds. All of the operating characteristics and capabilities provide operational envelope for the project to operate and either support the existing offtake agreements or operate in merchant a mode (many times it is both). Although most capital equipment expenses are paid up front, end of life responsibilities will only happen far into the future, with little existing evidence to date as to the validity of the current assumptions. Other project level issues such as operating contracts and risk management strategies will take place over the life of the unit, and thus will need to be evaluated over time as changing usage profiles will affect costs and project risks for a successful operation of the facility.

4.1. End of Life

As capital providers learn to account for all components of energy storage project financing, end-of-life costs are becoming an important component to address. Early estimates were sometimes wildly optimistic, but a slow but growing level of experience is providing a more refined range for total costs. For planning purposes, current estimates for the end-of-life costs for a lithium-ion battery system range from 10% to 15% of the initial capital cost of the system. For instance, the battery life-cycle management company Renewance²¹ estimates the cost for dismantling, shipping, and recycling a 10 MWh lithium-ion based project at over \$474,000, or nearly \$50/kWh. These costs will vary by technology and can rise for large scale energy storage systems that have a large portion of civil work.

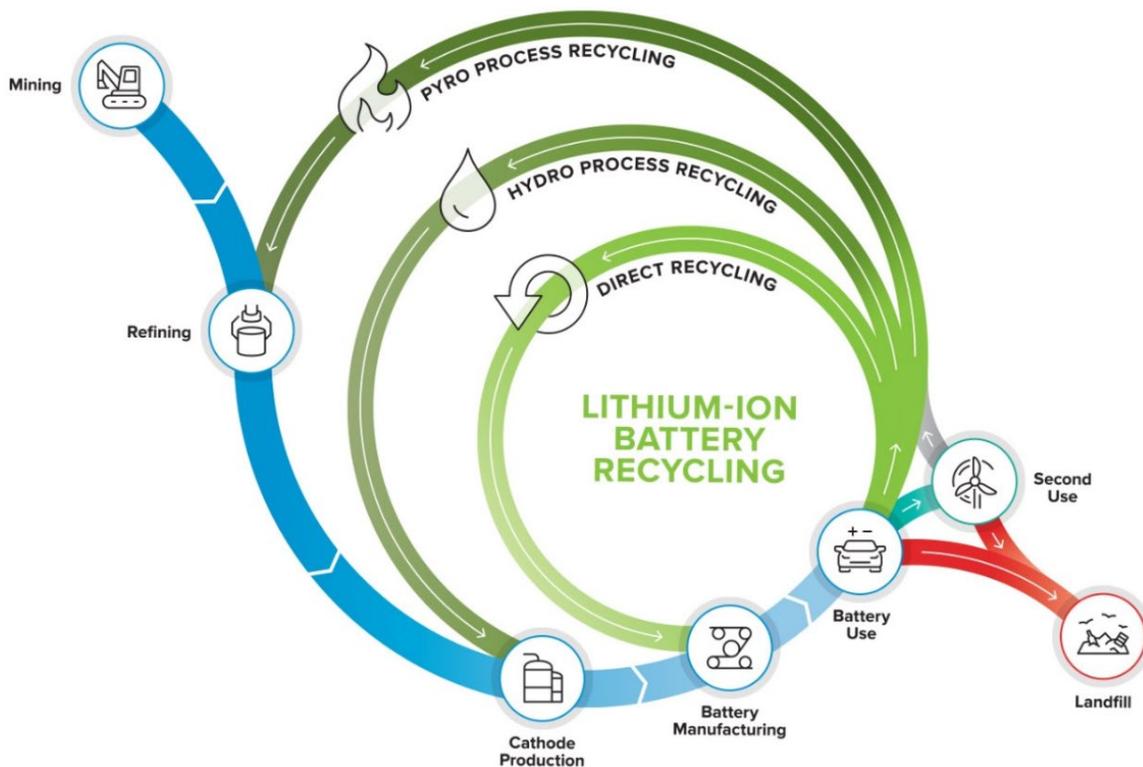


Figure 4-1. Circular Economy Pathways for EV Batteries

Source: ReCell, Argonne National Laboratory

Although the processing costs for removing and dealing with the project's equipment are becoming more understood, there still remains room for additional cost reductions, and possible reclaimed value from the materials. Currently, low volume of lithium-ion recycling hampers cost reductions through scale, but the increase in vehicle batteries usage promises to warrant additional investment so incremental advanced in current process and automation are expected, with the potential for lower cost process remain as the technology improves. Other markets are a good example that more can be done, as roughly 90% of lead acid batteries are recycled.

The potential value of reclaimed materials continues to be in flux due to a number of issues. First, the capability of the process equipment can generate different quantities of valuable metals. Secondly, the rise in the popularity of LFP based cells is driven by lower initial costs, but also then lack valuable reclaimable materials such as cobalt. The value of recycled materials will never be a deciding factor by developers in choosing a battery supplier, but as the industry matures, it will feed into the overall decision process.

This end-of-life decision contains three parts: Decommissioning, Transportation, and Disposal.

4.1.1. Decommissioning

Decommissioning of the energy storage facility concerns with dismantling of the on-site equipment and returning the site/location back to at least a brownfield state. This can roughly be described as the construction/commissioning process in reverse, including the removal of the battery systems, enclosures, HVAC, and associated power electronics and electrical connections. As with any other asset within the power sector, the decommissioning process involves dismantling the ESS enclosure and equipment and removing it from the site in compliance with applicable federal and local rules that govern the safe transport and disposition of used equipment or waste.

A central issue in end-of-life planning for energy storage assets is who bears the legal and financial responsibility for the project's equipment once the ESS a facility completes its operating life. Currently, the U.S. EPA links these responsibilities to the project owner. Increasingly, State governments and even Utilities are also requiring the owner to bear this responsibility. As such, in the project development contracts, typically the decommissioning of the facility is either tasked to the EPC that constructed it, or the contracted O&M provider.

Support for project developers is coming from a variety of government sources. For instance, the New York State Energy Research and Development Authority (NYSERDA) has published the *New York Battery Energy Storage System Guidebook for Local Governments*²². This Guidebook contains a model decommissioning plan for local governments planning the deployment of energy storage projects. This model decommissioning plan incorporates a number of components, including a narrative description of the decommission plan, an estimated operating life of the energy storage system, an estimated decommissioning cost, an adequate and secure funding mechanism for the decommissioning, and plans for removal of damaged energy storage modules.

Because there are a number of unknown variables in a process that is not slated to begin for 10 or 20 years, some degree of futureproofing is incorporated in the emerging decommissioning requirements to address current and potential future requirements. Some issues are easier than others, such as naming a specifically contracted firm, that, if in the future cannot perform the duty, another firm is contracted for the service. To ensure there is sufficient funds available for whatever firms that will perform the service, an independent sinking fund should be established to fund the future work. Other issues are more difficult as the plan must address what the future physical status

of the project will be. Most variable is the possible future regulatory changes, and whether existing facilities would be grandfathered into existing regulatory rules or not.

4.1.2. Transportation

After deconstruction and removal of the project's equipment from the site, the components of the energy storage system will be transported to a facility for disposal. The transportation of the various components will need to be done in accordance with the controls and regulations of the type of materials, and with the understanding that regulations in the future will probably be more stringent for the transportation of caustic chemicals, along with partially energetic chemical devices. For this reason, the batteries are typically the primary area of concern for transportation as the remainder of the components are electric equipment. The transportation of energy storage system components will generally conform to a reversal of the original equipment's initial transportation to the site, but to a proper disposal location.

Transporting partially energized lithium-ion batteries can pose a fire risk, either from puncture or short circuiting. During transportation, batteries being transferred to a recycling or disposal facility must be completely discharge. Other batteries being transferred to a refurbishment center maintain some degree of charge during transportation. The transport of batteries is governed by U.S. Department of Transportation (DOT) which classifies batteries as "Class 9" miscellaneous hazardous material.

Within the United States, a number of federal regulations apply for the transportation of batteries. According to PRBA²³ they include:

- 49 CFR Subchapter C – U.S. Hazardous Materials Regulations.
- 49 CFR 173.185 – U.S. Lithium Battery Regulations.
- 49 CFR 172.102 – Special Provisions 130 and 340 applicable to dry cell batteries and nickel metal hydride batteries.
- 49 CFR 173.159, 173.159a – U.S. Lead Acid Battery Regulations.

4.1.3. Disposal

Disposal of the energy storage system's equipment is the final end-of-life decision. There are essentially three areas of focus here: refurbishments, recycling, and the disposal of waste to an appropriate final location.

4.1.3.1. Refurbishment

Refurbishment of the project's equipment will vary due to the type of equipment. The primary component for refurbishment, re-use, or "second-life" is the battery. This discussion will deal primarily with the lithium-ion battery systems. Since this activity occurs at a facility that will be taking in a variety of equipment streams, it is important to sort the batteries by chemistry (LFP, NMC, etc.)

The refurbishment facility must first ensure that the correct type of batteries flow into a given refurbishment process, including separating different types of lithium-based chemistries, such as lithium iron phosphate (LFP) versus lithium nickel manganese cobalt (NMC). Within the facility, the cells are dismantled from the modules into the individual batteries. Testing is then required for all of the cells so that they can be reassembled into new modules with other cells with as similar a life-

status as possible. Some cells will not be a candidate for reuse and will be sent to the recycling process.

4.1.3.2. Recycling

Sorting batteries that are being sent into a recycling process is the first step to ensure that same-chemistry batteries are being fed into the system. The process of handling and processing cells from vehicles and stationary facilities is rapidly maturing and is expected to continue to evolve as the scale of potential resources grows. Cells from the automotive industry are expected to be the largest component of the supply chain as the transportation industry is a far larger market. Recycling efforts, especially for lithium-ion cells, are also expected to be dominated by the focus on the automotive market. This means that cells and modules in the stationary energy storage industry are expected to be included in the resource stream derived from vehicles as the recycling supply chain will be optimized for vehicular batteries.

Today, there are two primary commercial pathways for recycling batteries: the most common being pyrometallurgical process, and the hydrometallurgical process. Pyrometallurgy is a smelting process, allowing for the separation of the different valuable components through well understood metallurgical process. Hydrometallurgical is a chemical process that removes the valuable component materials through chemical leaching. Both processes have their own advantages, and are expected to gain adherents through what end result is desired.

4.1.3.3. Internment

Final disposal of remainder materials is currently governed by the handling and disposal regulations for chemically active and/or hazardous materials. As the scale of the vehicle battery market drives far higher levels of disposal needs, and as landfill space continues to be at a premium, these added costs for final disposal are expected to drive the effort towards greater recycling—or the transformation of remainder material into an inert form and composition that's suitable for regular landfill disposal.

4.2. Offtake Contracts

The growth of the energy storage market has expanded the number and type of stakeholders wanting to contract for the benefits of energy storage projects without owning the asset. No single offtake agreement exists for energy storage project financing, leading the energy storage market to borrow or adapt a number of standard contracts for other parts of the electrical power industry, while making some adjustments for the specifics of the energy storage industry. Off-take agreements provide the stable cash flows critical bankable project financing. The level of revenue certainty is effectively a trade-off between certainty and profitability. Many contracts for entities wanting to utilize the capabilities of assets have the features of contracts such as:

- **Take or Pay Contracts:** Take or Pay Contracts requires the offtaker to pay for the products on a regular basis whether or not the offtaker actually takes delivery of the products.
- **Take-and-Pay Contracts:** Take and Pay Contracts requires offtaker only pays for the product taken on an agreed price basis.

Offtake contracts for energy storage facilities typically follow standard power purchase agreement (PPA) structures as they allow for variability in the underlying contract details based upon an agreed upon performance criteria. There are many criteria to these, including contract terms, fixed and variable compensation components, cost escalators, capacity, range of possible energy throughput,

penalties, availability, etc. These areas typically fall into the front of the meter (FTM) market and behind the meter (BTM) market.

As the market continues to evolve, new offtake contracts are expected emerge and evolve. For that reason, current contracts must deal with the potential for change in the regulatory environment where the project operates. The role of the contract is to primarily define the party responsible for any additional charges or change in the performance capability of the project.

4.2.1. Front-of-Meter (FTM) Contract Structure

Offtake contract structures for individual large scale storage systems, or multiple smaller ones acting in concert within the contract, take advantage of the significant effort in power sector contract development. As the deployments of energy storage assets increase, developers of offtake agreements are increasing greater detailed language to assign responsibility for all possible occurrences to the appropriate party.

This development utilizes the standard contract issues such as schedule guarantees, curtailment, performance guarantees, defaults, liability limitations, etc. However, since these standard contracts were designed with thermal, solar, or wind projects in mind, care is required to investigate operating and performance attributes that are different with regard to energy storage assets and make the appropriate change to the metrics to qualify the area of responsibility. This focus also impacts those possible future contractual operating issues that have not been identified in the current contract, leaving open the area of responsibility. There are a number of current structures for FTM offtake agreements, including the tolling agreement and capacity agreement.

4.2.1.1. Tolling Agreements

In a tolling agreement, the owner/operator are responsible for project operation during the contract period. The offtaker owns the electricity used to charge the energy storage system and exercises full authority to dispatch the charging or discharging of the system acting as the scheduling coordinator for the system from the grid's perspective for its own benefit (capacity, energy, services, etc.) within specified technical or contractual limitations. The offtaker pays a fixed monthly fee, such as a capacity charge to use the storage facility's capacity, plus a variable operating charge on the energy throughput of the unit. The offtaker is typically thought of as a utility, but increasingly can be a number of other market players.

For operating the facility, the owner/operator receives a capacity payment (adjusted by availability and round-trip efficiency) and a variable O&M payment based on the amount of energy throughput. Energy needed for station service is separately billed to the operator. The fixed capacity charge to the offtaker may be subject to reduction for decreases in capacity, availability, or efficiency of the project.

4.2.1.2. Capacity Agreement

The capacity service agreement is similar to the tolling agreement, but here the owner/operator developer is the owner of the electricity, and is responsible for all costs, including the charging cost. The offtaker pays a fixed monthly fee for the ability to utilize the output of the system for capacity, energy, services, etc. within specified technical or contractual limitations of the energy storage system. These capacity service agreements transfer more of the project risk to the owner/operator, but also provide more of a possible upside revenue potential. For instance, if the offtaker is contracting for only capacity, then the owner/operator may be able to sell additional services into

the market in addition. This strategy will only work if the owner/operator a firm understanding of the system's costs and performance and knows how to apply them to market opportunities (or gets lucky). This structure is often used when the offtaker (e.g., a utility) seeks to contract for resource adequacy benefits or other capacity services.

Because of the evolving nature of the industry, contract terms are not always as specific as they need to be. This is of special concern when there are fixed formulas that form the basis for compensation. For instance, availability of the facility may not incorporate periods out of the control of the owner/operator, such as force majeure events or grid curtailment events. Also, care should be made to ensure that the weights and values ascribed to different capacity attributes are understood allow flexibility in the event of a change in relevant laws.

4.2.2. Behind the Meter (BTM) Contract Structures

Behind the meter (BTM) energy storage assets can provide revenue generating and revenue savings opportunities, so the contract structures need to be able to take both of these operating strategies into account. This can become complicated, as both activities can occur during the same deployment. Also complicating these issues is activity in the wholesale market opportunities would follow federal regulations, while activities in the retail market would be based on utility-based programs, which follow state regulations.

Wholesale market opportunities for distributed energy storage assets are poised to grow significantly when FERC Order 2222 is finally adopted. FERC order 2222²⁴ was approved on September 17, 2020. This Order is designed for distributed energy resources (DERs) to be able to compete on a level playing field in the organized capacity, energy and ancillary services markets run by regional grid operators. This Rule will allow DERs to participate alongside traditional wholesale market resources in the various ISOs/RTOs through aggregation in order to satisfy minimum size and performance requirements that individual units may not be able to meet individually. As wholesale operations, the contract structure would typically follow one of the FTM contract structures, but new structures could emerge as the Order goes into effect.

Contract structures for BTM energy storage assets acting to provide revenue savings are based off of the experience in the energy efficiency industry, where very mature contract structures have been developed. The Energy Savings Performance Contract (ESPC) is the central financing structure for Behind-the-Meter (BTM) energy storage projects and defines the term and requirements for the project. The ESPC structure has been used widely throughout the energy efficiency market to help customers pay for energy efficiency upgrades to their facility through a portion of the cost savings over a set time period, eliminating the need for the customer to pay up-front for the desired project.

Project developers/operators offering these types of contracts to customers usually arrange the financing from a 3rd party financing company, with the contract typically in the form of an operating lease. In this way, the ESPC is an offtake contract defining a turnkey service for the scope of work desired by the site owner. The contract provides for guarantees that the savings produced by use of the energy storage assets will be sufficient to finance the full cost of the asset, plus a profit margin to provide a return on investment for the developer/operator. Two of the most widely used energy savings performance contracts between project developers/operators and their customers in the energy storage market are the Demand Response Energy Storage Agreement (DRESA) and the Demand Charge Shared Savings Agreement (DCSSA).

4.2.2.1. Demand Response Energy Storage Agreement (DRESA)

In the Demand Response Energy Storage Agreement (DRESA) structure, a developer/operator is compensated by the local utility for providing capacity for demand response programs through aggregating a number of customer sited energy storage assets operating as a virtual power plant (VPP). These contracts are highly sought after by project developers/operators as the capacity contract with a utility provides virtually no counter-party risk, leaving the performance of the system—aggregating software and energy storage hardware—as the area of operational risk in the contract.

Payment is provided to the developer/operator in fixed monthly payments. Typically, the asset owner will also be offered a fixed fee for use of the asset. If there is a developer/operator between the asset owner and the utility, they will need to ensure that the contractual liabilities of having the asset available does not leave them exposed if the asset is not able to participate in the desired for any reason. This particular contract is generally not for exclusive use of the asset, but rather only as part of a demand response program. For this reason, the energy storage asset may be used by the owner of the asset (be that the developer/operator, or the site owner) for other applications. Care should be taken to ensure that the asset is not enrolled into another program that could conflict with the demand response program.

4.2.2.2. Demand Charge Shared Savings Agreement (DCSSA)

The demand charge shared savings agreement (DCSSA) contract aligns more closely to the typical energy savings performance contract used to finance energy efficiency building retrofit contracts. These contracts provide for service cost reductions based on the performance of the energy storage system. Here, the energy storage asset is used to reduce demand charges by powering the peak demand of the customer at specific times of the month.

This agreement is thus wholly behind the meter and between the developer/operator and the site owner. Variations on the contract structure could allow for either the developer/operator to own the asset, or for the site owner to own the energy storage asset but is much more common to be owned by the developer/operator and offered the activity of the asset as a service. The demand-charge savings are split between the customer and project company under a shared-savings model. Alternatively, the customer pays a fixed monthly subscription fee in return for guaranteed savings. This provides revenue certainty for the project company, but it eliminates upside potential.

4.3. Project Contracts

Beyond the critical off-take contracts, a number of other project level contracts are essential for a successful, profitable, and risk minimized operation of an energy storage facility. These include EPC contracts, O&M contracts, warranties, and performance guarantees. These different contracts act as capstone agreement for the particular area of the project in question, requiring a clear understanding of what issues and concerns exist from the cell level and system level would impact the project's reliable operation.

4.3.1. Engineering, Procurement & Construction (EPC)

Energy storage project developers typically contract with an Engineering, Procurement and Construction (EPC) firm in order to coordinate the construction and commissioning of an energy storage facility. The EPC firm typically has significant in-house technical capabilities to provide the most complex components, but often hires electrical contractors and specialized suppliers to

provide specific aspects of the scope of work. The EPC contract aims to both deliver the project according to the schedule while also limiting opportunities for the different parties to claim for other's responsibilities for the cost overruns. In this way, the EPC acts as a single point of responsibility for ensuring the deployment happens both on time and is technically capable of performing the intended duty cycles.

EPC contracts are designed to clearly allocate responsibility of critical contract issues between the project developer and the EPC firm. These issues are typical of contractual risk found in the power industry in the construction and commissioning of power facilities. However, due to the more complex design and operation of the energy storage system, these issues merit special attention when identifying responsibility. This is of even greater concern for all parties when contemplating a fully wrapped EPC contract, which is prevalent / increasingly the norm in the industry.

Choosing the right EPC firm is important. Typically, EPCs are brought in for larger projects. As you move to smaller, less complex system, the system integrator and electrical contractor is many times able to handle the construction on site. Turnkey, fully wrapped EPC contracts knit together the various equipment supplier warranties, including battery, power electronics, and HVAC, to provide the owner with a single source of equipment and performance reliability for the project. This requires significant technical expertise as the EPC needs to ensure that the equipment can work as specified individually, ensure that they can work together as a system, and that they are able to perform the desired usage profile. These aspects are evaluated in the early engineering evaluation phase of the contract, as well as during the commissioning phase prior to hand-over of the completed project.

Liquidated damages (LDs) are common clauses in EPC contracts. LDs specify damages to the developer/owner if the EPC contractor fails to meet specified completion milestone dates or agreed upon system performance requirements. These are a common component of most power industry construction contracts. These damages are to provide some relief for the owner's lost opportunity costs and to defray the ongoing expenses during construction. Ideally, LDs should attempt to match the likely losses that a developer would suffer in the event of a delayed completion, and not attempt to be portrayed as a penalty as those can vary from jurisdiction to jurisdiction and will make the negotiations much more complicated.

Liquidated damages are generally applied for late delivery of the facility by the EPC by a specified date. There can be a series of milestones where different damages are applied, typically including substantial completion date, guaranteed commercial operation date (COD), and termination date. Generally, the liquidated damages assessed rise as time progresses, but they are generally constructed to not exceed the termination payment so as not to be portrayed as a penalty.

4.3.2. Operation & Maintenance (O&M)

Operation and Maintenance (O&M) contracts are an essential component of a successful energy storage project. Maintaining the facility in a proper working order is not just essential for longer term operational status such as assuring availability and capacity but is a critical component of a preventive maintenance strategy. Increasingly, they are a requirement for project financing, insurance, safety regulations, and warranty contracts.

The evolution of O&M contracts has been following the structure of typical power sector O&M contracts. For instance, in the early solar market O&M contract execution risks had ranked amongst the top concerns of equipment manufacturers, rating agencies, and investors in the early days of that industry. This concern is currently found in the energy storage market since O&M procedures are

far more complex. As the requirements of the off-take agreement becomes more stringent as the industry matures, a comprehensive O&M contract covering all of the necessary issues to maintain proper operation of the facility remains a concern.

4.3.3. Performance Guarantee

Performance guarantees are an agreement to ensure that energy storage systems meet the technical performance requirements found within EPC contracts or off-take agreements. An EPC agreement with a performance guarantee agreement includes detailed system performance testing during unit commissioning. Typical technical issues could include RTE, storage capacity (kWh), charge/discharge (C-Rate) capability, availability, ramp rate, etc.

In the off-take agreements, performance guarantee agreements are required by customers (to fulfill off-take agreement requirements) and lenders (to maintain payment) and are common in renewable energy projects where performance is many times simply related to energy production over a set period of time. These agreements require the developer (or a designated engineering firm) to be responsible for maintain the system's specified performance rating over the operating life of the facility (and usually aligned with the application needs, not the warranty). Depending on the need of the off-take agreement, they only need to be limited to a specific set of operational parameters. It should be noted that although they underlie the drivers of the financial contracts, they do not extend to the financial performance and success of the system.

4.4. Risk Management

Managing a project's financial risk exposure requires a deep understanding of not just technical issues on the equipment and markets, but also their impacts of their operation, and how the various market strategies can impact both potential revenues and costs. There are two areas of risk management strategies where the operations of the project will both be impacted, and impact other aspects of operating the facility: insurance and warranty coverage.

4.4.1. Insurance

Insurance is a means for protecting against financial loss. These policies are an integral component of operational strategy for power sectors facilities and are especially important for complex systems such as energy storage projects where factors such as design, operation, and market strategy are not just inter-related, but can have profound and non-linear impact on one another.

Insurance is an essential component of financial project strategies to design project risk management strategies that expand opportunities at a lower cost through leveraging the financial assets of the insurance firms. This risk management and allocation focus is especially important for energy storage project development to take account of unique technology, policy and regulatory, and market issues. Insurance companies reduce their own risk through detailed understanding of the technology, its operation, and interaction in the power market.

As more operational experience is gained, insurance firms will be able to provide better and more innovative risk management market strategies for energy storage systems at all levels of the industry. As the industry matures through a growing body of project development and operational history, the cost of insurance should continue to decline as additional performance data and loss experience help refine the loss potential evaluation of these firms. Lacking sufficient data in emerging industries like energy storage, insurance firms have long been a driver to promote better testing and Standards development (in both equipment, installation, and operation) to reduce insured loss through

performance degradation or failure. Better information provides these firms the ability to determine what the actual risk premium cost for a variety of project development choices. As the industry gains more experience, re-insurers (insurance for insurance firms) will get involved, reducing further the cost for insurance coverage.

4.4.2. Warranty

Warranties play an integral part of the operational strategy of an energy storage facility. Warranty coverage ensures asset owners that there is recourse from the OEM in the event that the product does not perform as stated. Warranty coverage is very important to project developers, insurance firms, and capital providers to reduce downside risk of the equipment not being available to support revenue generation.

Warranties provide an envelope of possible usage profiles for the project. As described in the EPC section 4.2.2, EPC's typically provide a full warranty wrap for the facility where they ensure that the equipment can work as specified individually, ensure that they can work together as a system, and that they are able to perform the desired usage profile. This warranty wrap then gives developers and capital providers a range of possible applications to pursue (more is always better) while also ensuring that you do not overtax the batteries (less is always better).

Warranty coverage will vary significantly based on the technology. This will run the gambit of providing 1-3 years of warranty coverage and then allowing the option to purchase 1-year renewals, incorporating the warranty into an overall O&M service or capitalizing the warranty for the designed lifespan. Incorporating the warranty into the purchase price is based on application and can last anywhere from 10 to 20 years.

The incorporation of the warranty into the capital cost of the energy storage system generally assumes a specified usage profile. Increasingly, many developers for larger systems are opting out of the optional extended warranty if presented the option in order to save the expense. This is important for the project's business strategy, for instance if you are utilizing a lease structure for clients of smaller residential or commercial systems, the capital providers may want the product under warranty. Therefore, many developers of larger systems must balance the need of capital providers for assurance of quality in the batteries chosen, impacting the choice in OEM suppliers. Warranty coverage should be thought of as more than just a cash expense for project development; it is a central component of a liability reduction strategy.

Warranty coverage is typically focused on three areas: manufacturing defect, performance, and availability.

4.4.2.1. Manufacturing Warranty

Manufacturing warranty coverage provides against manufacturing defect for the different components (batteries, HVAC, power electronics) of the energy storage system. These are important as an improperly manufactured cell can fail, possibly causing damage to surrounding equipment directly or in a cascade impact. As mentioned above, the duration and exact coverage will vary by technology, and OEM.

4.4.2.2. Performance Warranty

Performance warranty coverage ensures that the system will perform according to the performance specification details provided at purchase. This is typically an operating such as energy throughput over a set period of time, but the specifics may vary depending upon intended application. This is

typically conditional based upon the usage (cycle life, Depth of Discharge, C-Rate, etc.) and operating conditions (temperature, elevation, etc.). This is important as it will directly impact the choice in applications—not just in which ones are chosen, but in the stacking/ranking as some applications will absorb more of the available capability than others. Because of the significant difference in both technical design and manufacturing, this will vary by OEM.

4.4.2.3. Availability Warranty

Availability warranty coverage ensure that the unit is available to operate when the unit is dispatched. This area is of growing importance for systems targeted at providing capacity services into the market. The coverage is usually linked to the number of operations per month or year required, and have a lifespan typically linked to the same as the performance warranty lifespan. This is important as this is related to the performance coverage, but distinctly separate, so the understanding of the various possible usage profiles needs to be undertaken with the goal of understanding the impact on each of these warranty coverages separately.

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5. ROLE FOR THE U.S. DEPARTMENT OF ENERGY

The U.S. Department of Energy has an important role in establishing a foundation of resources, analytics, metrics, and commonality among definitions to supporting improved operations & strategy. As the U.S. Department of Energy puts more resources toward improving the development of energy storage technologies, new and innovative programs are being developed, and existing programs are gaining additional support. Together, this will enable to U.S. Department of Energy to play a crucial role by providing a greater focus on Safety, Performance, Data and Analysis, and overcoming the Project Valley of Death.

5.1. Safety

The U.S. Department of Energy has considered Safety to be a critical foundational component of all aspects of energy storage project operation. For the last decade, the U.S. DOE has led the efforts to incorporate safety into all aspects of energy storage technologies and deployments.

5.1.1. Grid Energy Storage Strategy 2013

In 2013, the U.S. DOE released the Grid Energy Storage Strategy²⁵, which identified four challenges related to the widespread deployment of energy storage.

1. **Cost competitive energy storage technology** - Achievement of this goal requires attention to factors such as life-cycle cost and performance (round-trip efficiency, energy density, cycle life, capacity fade, etc.) for energy storage technology as deployed. It is expected that early deployments will be in high value applications, but that long term success requires both cost reduction and the capacity to realize revenue for all grid services storage provides.
2. **Validated reliability and safety** - Validation of the safety, reliability, and performance of energy storage is essential for user confidence.
3. **Equitable regulatory environment** – Value propositions for grid storage depend on reducing institutional and regulatory hurdles to levels comparable with those of other grid resources.
4. **Industry acceptance** – Industry adoption requires that they have confidence storage will deploy as expected and deliver as predicted and promised.

The second of these challenges, the validation of energy storage safety and reliability, continues to be an area of attention and focus for stakeholders across the industry.

Within the validated reliability and safety challenge, three areas were highlighted:

- R&D programs focused on degradation and failure mechanisms and their mitigation and accelerated life testing.
- Development of standard testing protocols and independent testing of prototypic storage devices under accepted utility use cases.
- Track, document, and make available performance of installed storage systems.

According to the report, the operational safety of large storage systems is a concern and will be a barrier in their deployment in urban areas or in proximity of other grid resources such as

substations. Design practices that incorporate safety standards and safety testing procedures for the different storage technologies need to be developed and codified.

5.1.2. DOE OE Strategic Plan for Energy Storage Safety 2014

Desiring to highlight the importance of Safety within the industry, the Department of Energy's Office of Electricity in 2014 worked with stakeholders from across the energy storage industry to develop the *Energy Storage Safety Strategic Plan*²⁶, a roadmap for grid energy storage safety that addresses the range of grid-scale, utility, community, and residential energy storage technologies being deployed across the Nation. The Energy Storage Safety Plan highlights safety validation techniques, incident preparedness, safety codes, standards, and regulations, and makes recommendations for near- and long-term actions.

Safety issues concern the operation of the facility from a number of avenues. Externally, seismic events, fire, freezing, and flooding are all important issues for site planning. Internal issues including fire and electrical are important for design safety. According to the DOE, this document was designed to address grid-side safety, while recognizing that the efforts undertaken will apply to other ESS applications, regardless of deployment location.

A key structure for the report was that safety of any new technology can be broadly viewed as having three intimately linked components:

- 1) a system must be engineered and validated to the highest level of safety possible;
- 2) techniques and processes must be developed for responding to incidences if they do occur; and
- 3) the best practices and system requirements must then be reflected standardized safety determinations in the form of codes, standards and regulations (CSR) so that there is uniform, written guidance for the community to follow when designing, building, testing and deploying the system.

5.1.3. Energy Storage Safety Working Group

Building upon prior efforts, the U.S. DOE's Office of Electricity established the Energy Storage Safety Working Group (ESSWG) involving stakeholders from across the energy storage industry. The goal is to address safety gaps, previously identified and prioritized by the Energy Storage Safety Preliminary Team (ESSPT), needed to support the timely and safe deployment of stationary energy storage systems.

According to the U.S. DOE, The DOE Energy Storage Safety Working Group²⁷ (ESSWG) provides a single location for information relevant to people and organizations engaged or with interest in R&D efforts in grid storage safety, ESS safety codes, standards, and regulations, and safety outreach to first responders and other stakeholders. The ESSWG enables timely deployment of safe energy storage systems consistent with the December 2014 DOE OE Energy Storage Safety Strategic Plan by following the framework outlined by the ESSPT, which specifically prioritizes the work needed to address gaps in the knowledge associated with energy storage system safety, and carrying out safety related research, education and training, technical support, and codes/standards development activities.

The activity of the ESSWG was to focus on the safety of all stationary ESSs, and projects to address the gaps will be organized and conducted through coordinated actions focusing on the priority gaps identified by the ESSPT in each of three ESSWG areas:

- Safety Validation and Risk Assessment
- Codes and Standards
- Safety Outreach and Incident Response

5.1.4. Codes & Standards

The U.S. Department of Energy supported the development by the Pacific Northwest National Laboratory (PNNL) of the Inventory of Safety Codes and Standards for Energy Storage Systems [PNNL-23618].²⁸ This has proven to be a key capstone of existing codes, standards, and regulations (CSR), and a fundamental framework for following efforts in the industry. The intent was for this report to cover all energy storage system technologies and installations.

According to the report, the purpose of the document is to identify laws; rules; model codes; and CSR specifications related to safety that could apply to stationary energy storage systems (ESS) and experiences to date securing approval of ESS in relation to CSR. This information is intended to assist in securing approval of ESS under current CSR and to identification of new CSR or revisions to existing CSR and necessary supporting research and documentation that can foster the deployment of safe ESS.

5.2. Cost & Performance

The U.S. Department of Energy believes that promoting a clear understanding of the cost and performance of energy storage technologies supporting common applications is crucial for customers and stakeholders throughout the Nation. This is no easy task as there are many different types of technology, that come in many different designs and sizes, that need to be optimized sometimes for specific usage profiles. Adding to this complexity is that “how” one uses an energy storage system many times impacts its lifetime performance and subsequent costs.

The U.S. DOE addresses this challenge in a number of ways. First, it sponsors the development of a number of reports and analyses to improve the visibility into the changing cost and performance of energy storage technologies. The DOE also promotes a more detailed investigation into the different possible applications to help define the usefulness of these technologies. Finally, the DOE supports the use of performance analyses and metrics as guides for policy decision making.

5.2.1. Reports & Analysis

Because of the complexity of the cost structure and system performance capabilities, different Offices and groups within the Department of Energy provide a number of reports and analyses on the cost and performance of energy storage systems. These different reports approach the cost of these technologies independently, providing a number of rigorous evaluations of these changing technologies.

As the commercial use of these technologies advance, more detailed and complex analyses will continue to be provided in order to provide end-users and policymakers with better insights for their decision-making needs.

5.2.1.1. Grid Energy Storage Technologies Cost and Performance Assessment

As demand for energy storage technologies continues to grow and evolve, it is critical to be able to compare the costs and performance of different energy storage technologies on an equitable basis.

For this reason, the U.S. Department of Energy tasked the Pacific Northwest National Laboratory to develop an annual cost and performance report for energy storage technologies, starting in 2020.²⁹

As part of the Energy Storage Grand Challenge, this report series is designed to be as representative of the full DOE's viewpoint and estimation of technology prices as possible. The Report series is entitled "Grid Energy Storage Technologies Cost and Performance Assessment" and provides a range of cost estimates for technologies in 2020 and 2030 as well as a framework to help break down different cost categories of energy storage systems. The analysis is accompanied by an online website³⁰ that makes updated energy storage cost and performance data easily accessible for the stakeholder community.

5.2.1.2. Energy Storage Pricing Survey

The annual Energy Storage Pricing Survey (ESPS) series published through Sandia National Laboratories (funded by the DOE Office of Electricity) is designed to provide a standardized reference system price for various energy storage technologies across a range of different power and energy ratings. This is an essential first step in comparing systems of the different technologies' usage costs and total cost of ownership. The final system prices are developed based on data from an extensive set of interviews with representatives across the manufacturing and project development value chain, plus available published data. This information is incorporated into a consistent methodology structure that will allow pricing information to be incorporated at whatever level it was obtained, ranging from component to fully installed system.

The Energy Storage Pricing Survey system pricing methodology breaks down the cost of an energy storage system into the following component categories: the storage module; the balance of system; the power conversion system; the energy management system; and the engineering, procurement, and construction costs. By evaluating each of the different component costs separately, a more accurate system cost can be developed that provides internal pricing consistency between different project sizes using the same technology, as well as between different technologies that utilize similar components.

5.2.1.3. Cost Projections for Utility-Scale Battery Storage

The National Renewable Energy Laboratory (funded through the DOE Office of Energy Efficiency and Renewable Energy) publishes a series of reports on energy storage technologies because of their central role supporting the continued expansion of renewable energy power plants.

In 2016, the National Renewable Energy Laboratory (NREL) published the report, *Cost Projections for Utility-Scale Battery Storage*³¹ with its first set of cost projections for utility-scale lithium-ion batteries. Those 2016 projections relied heavily on electric vehicle battery projections because utility-scale battery projections were largely unavailable for durations longer than 30 minutes. In 2019, battery cost projections were updated based on publications that focused on utility-scale battery systems³². The 2020 edition of the Report³³ updates the cost projections published in 2019. The projections in this work focus on utility-scale lithium-ion battery systems for use in capacity expansion models.

NREL utilizes the Regional Energy Deployment System (ReEDS) and the Resource Planning Model (RPM) for capacity expansion modeling, and the battery cost projections developed here are designed to be used in those models. Additionally, the projections are intended to inform the cost projections published in the Annual Technology Baseline (NREL 2019).

5.2.2. Applications

Energy storage systems are able to provide a wide range of services across the power grid. There are a wide variety of different applications that energy storage facilities can perform, sometimes single applications (less common), sometimes performing a variety of applications (at different times). As the technology continues to improve, and as market participants learn how to utilize these systems in the market, additional applications continue to be explored.

These applications may or may not have a widely accepted or clear way to generate value or revenue, however. Also, although the industry typically divides applications into different market segments, the evolving nature of how energy storage assets in different parts of the power grid interact with the market continues to blur, such as the growth in BTM assets becoming active in ISO markets for wholesale services. The following is a description of how energy storage systems can operate.

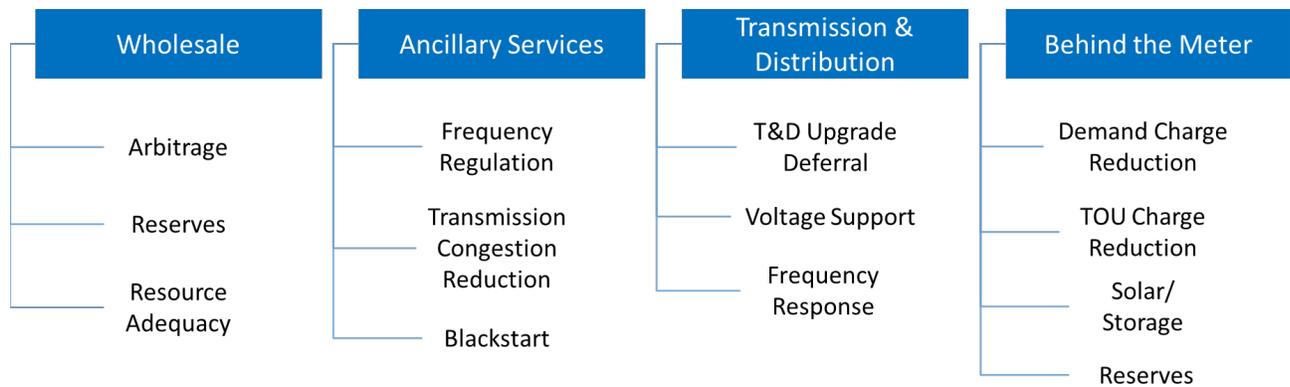


Figure 5-1. Energy Storage Applications

Source: Mustang Prairie Energy

Beyond simply listing possible applications, the U.S. Department of Energy’s Office of Electricity sponsored the development of a more detailed evaluation of the technical aspects and definitions of applications for energy storage systems. The Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems (PNNL-22010) was first issued in November 2012 as a first step toward providing a foundational basis for developing an initial standard for the uniform measurement and expression of energy storage system (ESS) performance. Based on experiences with the application and use of that document, and to include additional ESS applications and associated duty cycles, test procedures and performance metrics, a first revision of the Protocols reports was issued in June 2014 (PNNL-22010 Rev. 1). A second revision of this report was issued in April of 2016 (PNNL-22010 Rev 2 / SAND2016-3078 R)³⁴

According to the report, the Protocol provides a set of “best practices” for characterizing energy storage systems (ESSs) and measuring and reporting their performance. It serves as a basis for assessing how an ESS will perform with respect to key performance attributes relevant to different applications. It is intended to provide a valid and accurate basis for the comparison of different ESSs. By achieving the stated purpose, the Protocol will enable more informed decision-making in the selection of ESSs for various stationary applications.

The Protocol identifies general information and technical specifications relevant in describing an ESS and also defines a set of test, measurement, and evaluation criteria with which to express the

performance of ESSs that are intended for energy-intensive and/or power-intensive stationary applications. An ESS includes a storage device, battery management system, and any power conversion systems installed with the storage device. The Protocol is agnostic with respect to the storage technology and the size and rating of the ESS. The Protocol does not apply to single-use storage devices and storage devices that are not coupled with power conversion systems, nor does it address safety, security, or operations and maintenance of ESSs, or provide any pass/fail criteria.

5.2.3. Stakeholder and Policy Guidance

The U.S. Department of Energy utilizes available cost and performance data to provide guidance for stakeholders and policy makers concerning the use of energy storage systems. Increasingly, in addition to stand alone reports and analyses on energy storage technologies, energy storage analysis is being included in the standard reports provided for the entire industry, such as the EIA's Annual Energy Outlook. Other groups such as ARPA-E are using performance-based metrics to promote additional development of emerging technologies in new and innovative applications, such as the Duration Addition to electricitY Storage (DAYS) program.

5.2.3.1. EIA Annual Energy Outlook

Beginning with the Energy Information Agency's (EIA) Annual Energy Outlook 2021 (AEO2021), the EIA has begun incorporating energy storage analysis into the *Levelized Costs of New Generation Resources*³⁵. This is an important step for the technology, as the AEO is a critical annual publication for the entire energy industry.

According to the U.S. DOE, the Annual Energy Outlook explores long-term energy trends in the United States. Projections in the Annual Energy Outlook are not predictions of what will happen, but rather, they are modeled projections of what may happen given certain assumptions and methodologies. By varying those assumptions and methodologies, the AEO can illustrate important factors in future energy production and use in the United States. The EIA develops the AEO by using the National Energy Modeling System (NEMS), an integrated model that captures interactions of economic changes and energy supply, demand, and prices.

Incorporated into each release of the AEO is a stand-alone analysis on the Levelized Costs of New Generation Resources. According to the U.S. DOE, this annual paper presents average values of levelized costs for electric generating technologies entering service in 2023, 2026, and 2040 as represented in the National Energy Modeling System (NEMS) for the AEO 2021. Levelized cost of electricity (LCOE) is the estimate of the revenue required to build and operate a generator over a specified cost recovery period, and levelized avoided cost of electricity (LACE) is the revenue available to that generator during the same period. Beginning with the AEO2021, EIA includes estimates for the levelized cost of storage (LCOS) in addition to LCOE and LACE. All three values estimate the factors contributing to the capacity expansion decisions we modeled, which also consider policy, technology, and geographic characteristics that are not easily captured in a single metric. The build decisions in the real world and as modeled in AEO2021, however, are more complex than a simple LACE-to-LCOE or LACE-to-LCOS comparison presented in the paper because they include factors such as policy and non-economic drivers. Nevertheless, the value-cost ratio (the ratio of LACE-to-LCOE or LACE-to-LCOS) provides a more intuitive framework for understanding economic competitiveness between generation technologies in the capacity expansion decisions than is possible using either LCOE, LCOS, or LACE metric individually.

5.2.3.2. Duration Addition to electricity Storage (DAYS)

Within the U.S. Department of Energy, the Advanced Research Projects Agency-Energy (ARPA-E) advances high-potential, high-impact energy technologies that are too early for private-sector investment. When developing funding programs for these new and innovative technologies, however, it is sometimes then difficult to craft a financial performance metric that can help guide firms toward the goals that ARPA-E has.

According to ARPA-E, the Duration Addition to electricity Storage (DAYS) program was launched in 2018 to pursue new long-duration electricity storage (LDES) technologies with discharge durations that range from 10 to approximately 100 hours at rated power. Long-duration storage applications present new forms of technical challenges associated with exceptionally low lifetime cost requirements (including both capital and operating expenses), particularly for the energy storage media and related components. The primary objective of the DAYS program was the development of LDES systems that deliver electricity at a levelized cost of storage (LCOS) of 5 cents/kWh-cycle across the full range of storage durations (i.e., 10 to approximately 100 hours). This requirement results in a target lifetime cost that decreases with increasing storage duration, a marked divergence from many existing storage cost targets that focus on a single duration and thus a single cost metric.

The use of LCOS as a performance metric for project development is an important step. Rather than a technological performance metric, LCOS is an economic one, and as designed, lacking technological biases that imply one technology over another. Using tools such as the LCOS, government agencies such as ARPA-E can allow OEMs to develop their technology independently, while also providing direction as to the key performance capabilities they would like to see advanced, and thus financially support.

5.3. State Level Support

The U.S. Department of Energy produces many tools and resources in support of States and utilities incorporating energy storage technologies within their evaluation and planning. These include both efforts targeted at Integrated Resource Plans, and State governmental bodies that are looking to formulate their own plans for guiding energy storage development in their State.

5.3.1. Integrated Resource Planning

Integrated Resource Plans are a roadmap that utilities use to plan out possible electricity supply options to address expected demand needs. These are typically long-term in nature (20 year or more) in order to address the long-term needs of the customers, and the lead time required to build generation facilities. In support of this process, the U.S. Department of Energy's Office of Electricity supported the development of the report *Energy Storage in Integrated Resource Plans*³⁶ in 2019 by the Pacific Northwest National Laboratory. This report was designed to support the inclusion and integration of energy storage technologies into the possible resource mix by providing technical and economic pathways for energy storage assets to be compared with other resources on an even-handed basis.

According to the report, Energy storage deployments are increasing across the U.S., contributing to a more efficient, resilient, sustainable, and affordable grid. To continue this progress, it is imperative that utility integrated resource planning be updated to consider advanced energy storage as a viable option for system capacity. Energy storage costs are declining rapidly, and large-scale storage deployments are increasing. With electric utilities planning to invest billions of dollars in new and replacement capacity over the next several years, the time is now to include storage in resource

planning to ensure least-cost solutions for ratepayers and prudent long-term investments for reliability.

This report operates as a primer on Advanced Energy Storage in Integrated Resource Planning and shows how to appropriately include advanced storage in long-term utility resource planning processes through current examples. The report also included a set of up-to-date cost inputs, a summary of utility IRPs from 2016-2017 that examine energy storage, and a list of recent state regulatory decisions on including storage in IRPs.

5.3.2. Energy Storage Technology Advancement Partnership (ESTAP)

According to the Energy Storage Technology Advancement Partnership (ESTAP)³⁷, the program is a federal-state funding and information sharing project focused on accelerating the deployment of electrical energy storage technologies in the U.S. This program was developed since although energy storage can provide significant support to the realization of many States energy goals, projects demonstrating new technology or applications can be difficult to fund and initiate. Through this program, State goals such as the increased deployment of renewable energy, reduction of peak demand reduction, emission reduction, and grid resiliency and modernization.

The ESTAP program provides technical assistance and co-funding energy storage project opportunities States and the U.S. Department of Energy, Office of Electricity (DOE-OE), managed by Sandia National Laboratories, and administered by the Clean Energy States Alliance. Stakeholders for this program include State and municipal government officials, public utility commissioners, investor-owned utility management, OEMs universities, and project developers. These stakeholders will benefit from participating in the ESTAP program, including DOE support for their near-term projects, project- and policy-specific technical assistance, and networking with other groups in similar situations.

ESTAP conducts four key activities:

5.3.2.1. Project Deployment

The ESTAP program facilitates public private partnerships (PPP) and cooperation between State and Federal agencies to support energy storage demonstration project development. Some of the key areas include:

- Matching state-supported large-scale energy storage project proposals with the research needs of Sandia National Laboratories and DOE's Energy Storage Research program in the Office of Electricity
- Matching bench-tested energy storage technologies with federal/state supported demonstration projects to support innovative large scale energy storage deployment projects
- Providing DOE funding for generic engineering, monitoring and assessment, as well as engineering consulting services from Sandia engineers, in support of innovative energy storage projects
- Facilitating cost share for project deployment from states, utilities, foundations, and other stakeholders

5.3.2.2. Policy Development

The ESTAP program facilitates federal and state partnerships to support various state energy storage policy goals, programs and regulatory development by providing technical support in developing energy storage programs, policy and regulations, and expert testimony to legislative committees and in regulatory proceedings addressing energy storage development.

5.3.2.3. Analysis

The ESTAP program conducts analysis of energy storage technical and economic opportunities, in order to support development of energy storage markets, policy, and projects, including:

- Analysis and modeling of proposed project economics
- Analysis of proposed project technical specifications and operational parameters

5.3.2.4. Information Dissemination

The ESTAP program disseminates information on energy storage technologies and projects to various stakeholders through public communications, including webinars, conferences, case studies, press releases, and white papers/reports.

5.4. Data & Analysis

Providing clear technical and market data is an essential role for the U.S. Department of Energy as it attempts to help stakeholders and policymakers better insights and strategies to improve the operations of energy storage projects supporting a variety of usage profiles. Critical efforts here include the development of standard and open databases and valuation analysis models.

5.4.1. Data

Reliable, comprehensive, and easily accessed data source are an imperative component of improving the operational performance of energy storage projects. The US Department of Energy is developing standalone resources such as the *Global Energy Storage Database*³⁸ and incorporating the reporting on energy storage projects into existing surveys, such as in the Energy Information Agency.

5.4.1.1. Global Energy Storage Database

A critical requirement to improving reliable project and portfolio valuation is to expand the amount of comparable data on existing projects operating in the marketplace. There are a number of proprietary energy storage project databases on the market, but the U.S. Department of Energy has provided a publicly available database on projects operating across the globe, establishing a basis for improving pricing visibility for energy storage projects.

The *DOE Global Energy Storage Database* (hosted at the Sandia National Laboratories website) provides free, up-to-date information on grid-connected energy storage projects worldwide. Users can search the database by using a host of attributes, including region, technology, service territory, benefit stream, and other project statistics. As the database has grown, data visualization tools have been added to help users analyze the data. Competing project database offerings exist from various consulting firms, but the Global Energy Storage Database remains the most widely available resource to the public.

The U.S. Department of Energy’s planned path forward for the *DOE Global Energy Storage Database* is to continue to expand the number of projects included, deepen the level of information available on each project, and add additional analysis capabilities to make the database more usable and effective. Through this continuing effort, the *DOE Global Energy Storage Database* will maintain its status as the primary basis for the analysis of energy storage projects.

5.4.1.2. U.S. EIA

As the number of deployed energy storage projects grow, more Offices and Agencies within the U.S. Department of Energy are incorporating these projects into their reporting, improving the transparency into the deployed assets, and their operating status. The U.S. Department of Energy maintains survey forms to collect asset and operational data about the U.S. energy industry. These forms are the basis for key reporting on the industry, so as the EIA collects more information about their deployment, stakeholders can rely on the EIA data to be reliable. Two survey series in particular have been important for reporting on energy storage projects, EIA-860, and EIA-861.

The EIA-860 survey family collects generator-level data about existing and planned units at electric power plants with 1 megawatt or greater nameplate capacity. Data from this survey is used in the Electric Power Annual. By incorporating energy storage assets into these standard reporting forms, developers can gain some information about the current state of the market in the specific region they are contemplating the development of an energy storage project. Based off of data from EIA-860, The U.S. EIA produced the report “U.S. Battery Storage Market Trends” in May 2018. The “U.S. Battery Storage Market Trends” report examines trends in U.S. battery storage capacity installations and describes the current state of the market, including information on applications, cost, as well as market and policy drivers for recent battery storage installations.

The EIA-861 survey family collects utility information such as peak load, generation, electric purchases, sales, revenues, customer counts, energy efficiency, demand response, net metering programs, and distributed generation capacity. This will allow stakeholders to track ownership of these assets over time.

5.4.2. Valuation Analysis

Ensuring that stakeholders and policymakers are able to derive a rational value for a particular energy storage project is a central imperative of the U.S. Department of Energy. The U.S. DOE has approached this in both developing analytical models and larger frameworks in order to support these valuation analysis efforts. The U.S. DOE has approached this for over a decade, targeting issues such as flexibility, market opportunities drivers and synergies, and barriers as key issues to address.³⁹

A typical project modeling framework for energy storage technologies has four key stages:

1. Identify potential products and services in a particular location/market
2. Evaluate optimal technology and design configuration to provide product / service
3. Model application/revenue stacking strategy to optimize storage offering
4. Compare economics of storage to available options (generation, T&D, non-wires)

Each one of these steps have their own challenges. For instance, many new market opportunities for energy storage projects are still emerging, so have a long-term stability as to their size and relative value is difficult. Although developers are quickly gaining better insight into these possible markets,

they are still evolving rapidly. Some emerge through regulatory changes as well. Since fundamental changes in the electric power industry are still expected what the possible products and services are, and what their value is will continue to change, sometimes rapidly.

Optimizing the design configuration for the particular usage profile is the next critical stage. This can either be done as a single optimization approach, using a standard sized energy storage system and determining what services it is able to provide, or an iterative approach where differently sized systems are evaluated against a differing basket of possible applications. This should be seen as more of a technical than economic analysis.

Determining the economic value of the project as it provides the market services is the next stage in analysis. This entails evaluating the technical capabilities of the system design from the earlier stage against the market opportunities to derive the highest value approach for the unit. Because of the multiple applications available to the project, there needs to not just be an analysis of what applications are evaluated, but how much time is spent supporting each one. This value stacking analysis is critical to energy storage project modeling optimization. Unfortunately, since the economics and technical capabilities of an energy storage system are closely intertwined, leading to a possible need to redo stage 2 and 3 in order to determine if the value of the system improves with some design capability changes.

Finally, evaluating the energy storage project's economics against alternatives is an important final step. For independent developers, this stage can be accomplished through evaluating standardized bids from other technologies when competing for proposals. For Utilities requiring more detailed and provable least cost analysis for PUC filings, the analysis framework would be more pronounced.

5.4.2.1. QuEst (SNL)

Sandia National Laboratories has developed QuEst⁴⁰, an energy storage project simulation model to evaluate the economic impact of various market applications. The model is open source, allowing users the freedom to add additional modules, or change the base code in order to tailor the model more closely to their needs. QuEst is designed to be used in system planning activities by running a variety of simulations to determine the maximum possible revenue from a specific system.

According to Sandia National Laboratories, the current application list includes:

- **QuEst Data Manager** — Manages acquisition of ISO market data, US utility rate data, commercial and residential load profiles, etc.
- **QuEst Valuation** — Estimates potential revenue generated by energy storage systems providing multiple services in the electricity markets of ISOs/RTOs
- **QuEst BTM** - Estimates the cost savings for time-of-use/net energy metering customers using behind-the-meter energy storage systems

5.4.2.2. Battery Storage Evaluation Tool (PNNL)

Pacific Northwest National Laboratory (PNNL) has developed two models designed to identify the sizing and usage of energy storage systems in order to support the greater deployment of energy storage technologies. The two models are the Battery Storage Evaluation Tool⁴¹, and the Optimal sizing Tool for Battery Storage. These tools are designed to be used by a variety of users supporting policy and utility planning, project develops, and customers to evaluate the cost effectiveness of energy storage at locations on the power grid.

5.4.2.3. REopt™ (NREL)

The National Renewable Energy Laboratory (NREL) developed the REopt model to evaluate the project economics of solar plus storage deployments in different regions of the United States. REopt⁴² is a decision support tool for optimizing energy systems in behind the meter situations such as commercial buildings, campuses, communities, and microgrids. REopt develops the optimal selection of system sizing and capability among a series of choices based on specific electrical and thermal loads required for the building. The pool of potential technologies includes a variety of distributed energy sources and incorporates both their economics and technical performance capabilities.

5.4.2.4. System Advisor Model (NREL)

The System Advisor Model⁴³ (SAM) was developed by the National Renewable Energy Laboratory (NREL) as a project-based performance and financial model to facilitate decision making for groups involved in the renewable energy industry. Groups intended to benefit from the model include project managers and engineers, policy analysts, technology developers, and researchers. According to the SAM model website, the System Advisor Model “makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters that you specify as inputs to the model.”

5.4.2.5. Pumped Storage Hydropower Valuation Guidebook

Long duration energy storage is viewed as an important future resource for the power grid to enhance reliability and flexibility. To that end, the U.S. Department of Energy’s (DOE’s) Water Power Technologies Office (WPTO) funded development of a Pumped Storage Hydropower Valuation Guidebook⁴⁴ to improve the understanding by stakeholders of the potential value in utilizing the new generation of pumped storage hydropower (PSH) facilities.

The Guidebook contains a number of key elements. It begins with a general overview of valuation decision analysis methods and approaches as they pertain to PSH facilities. The Guidebook then delves deeper into the steps involved in the proposed framework. The Guidebook then provides extensive technical detail on various methods and approaches that can be used to assess, quantify, and estimate the value of different PSH services and contributions to the grid. Finally, The Guidebook provides insight into how to value the different applications that can be supported (also known as value stacking). In addition to the Guidebook, more extensive analysis and tools is expected from the Water Power Technology Office in support of PSH technologies.

5.5. Industry Analysis

The U.S. Department of Energy supports a variety of industry analysis focused on supporting stakeholders understand the impact of operations and different market strategies have on energy storage projects. Key areas of support include Policy, Market, and Economic Analysis.

5.5.1. Policy Analysis

The U.S. Department of Energy understands that policy decisions have a fundamental impact on the energy markets in general, and on the introduction of a new technology class in particular. The level of impact increases when one realizes that many of the market applications for energy storage must be formulated through policy efforts at the State and Federal level. For this reason, the U.S. Department of Energy sponsors research at the Sandia National Laboratories to educate

stakeholders across the industry and policy makers to stay informed on the changing nature of public policy impacting energy storage. One such study, “Energy Storage Policy Summaries for the Global Energy Storage Database” [SAND2019-11175 C]⁴⁵ offers prototypes summaries of public policies in leading States. The goal is to expand on this work, and prepare summaries for all 50 states, and then maintain an updated report at the Global Energy Storage Database in order to provide a resource for the industry so public utility regulators can call upon to inform policymaking in their own jurisdictions.

5.5.2. Market Analysis

The U.S. Department of Energy realizes that a key first step in determining a sound market strategy to follow with an energy storage asset is to understand the broader market for energy storage technologies and potential opportunities. Because of the growing scale of the energy storage market, a number of private market reports have emerged. However, none of these reports were designed to be comprehensive for all market and technologies, and more importantly, free. Therefore, the U.S. Department of Energy in 2020 began publishing the *Energy Storage Market Report (Year)*.⁴⁶

According to the U.S. DOE, the purpose of this report is to summarize published literature and available data from the previous year to provide an update on the status and drivers of the current market, and expectations for where the industry is headed over a time interval of generally 10 years. These market status and drivers cover the Global market overall, and the U.S. market in particular for the stationary energy storage market and the transportation market. Although lithium-ion battery technology dominates, multiple technologies are covered as they are deemed commercially viable.

As the energy storage industry matures and grows, the Energy Storage Market Report will provide stakeholders from across the industry and policymakers a consistent and comprehensive resource to evaluate the market.

5.5.3. Economic Analysis

The Electricity Markets & Policy (EMP)⁴⁷ group at the Lawrence Berkeley National Laboratory (LBL) informs public and private decision making within the U.S. electricity sector through independent, interdisciplinary analysis of critical electricity policy and market issues.

According to the EMP Group, the EMP aims to make an impact through rigorous analysis of the policy, economic, and technical issues that support a successful transition to a clean, efficient, reliable, and affordable electricity sector. To do this, the EMP employs a range of interdisciplinary methods and tools appropriate to the topic at hand, including primary data, economic, and statistical analyses; modeling; and survey and interview-based research.

The Group provides insight and information to public and private decision makers through direct technical assistance, publications, and presentations. The EMP Group provides support for economic analysis along three important areas, including Utilities, Front of the Meter Solar and Storage, and Behind the Meter Solar & Storage.

The EMP Group supports Utility use of energy storage and incorporation into their plans through a number of studies and events. In order to support wide range of stakeholders, the group supports a variety of webinars, including the Western States Training Webinars on Integrated Distribution System Planning⁴⁸ where energy storage was incorporated into a variety of planning segments, including:

- Integration, Management and Control of Distributed Energy Resources (DERs)

- Planning for Grid Modernization and Resilience and Investment Economics
- Planning for Energy Storage
- Western States Roundtable Policy and Regulatory Issues for Utility Investments in Grid Modernization

The EMP Group supports Front of the Meter (FTM) solar and storage deployment through a series of studies. A recent study, “Are coupled renewable-battery power plants more valuable than independently sited installations?”⁴⁹ evaluated the pricing volatility differences between nodes within electricity markets impact the system value of coupled renewable-battery projects as compared to independent VRE and battery installations. Therefore, roles exist for independent and coupled projects from a system optimization perspective. Another recent report, Drivers of the Resource Adequacy Contribution of Solar and Storage for Florida Municipal Utilities⁵⁰ highlights simple methods for estimating the resource adequacy contribution of solar and storage. These are helpful for utility planners as simple estimating is important first step for utilities to gauge policy impacts before moving to a more detailed and resource-intensive modeling.

The EMP Group also supports Behind the Meter (BTM) solar and energy storage deployment through a series of studies to understand how solar PV can impact demand charges. According to a recent report, Synergies of Solar + Storage for Managing Demand Charges⁵¹, this latest analysis estimates demand charge savings from solar in commercial buildings when co-deployed with behind-the-meter storage, highlighting the complementary roles of the two technologies. The analysis is based on simulated loads, solar generation, and storage dispatch across a wide variety of building types, locations, system configurations, and demand charge designs.

5.6. Overcoming the Project Valley of Death

Energy storage technologies face a critical hurdle after they prove successful operation of their technology, a project development valley of death. Most are familiar with the technology valley of death, so it is useful to look at that challenge, and see what lessons can be learned. As can be seen in Figure 5.2, the technology valley of death highlights the need for a significant amount of capital resources to maintain even small amounts of progress as it moves through the later stages of the technology development segment. This is driven by the need to scale manufacturing capability, develop larger, more complete systems, and absorb and internalize the lessons learned from failures.

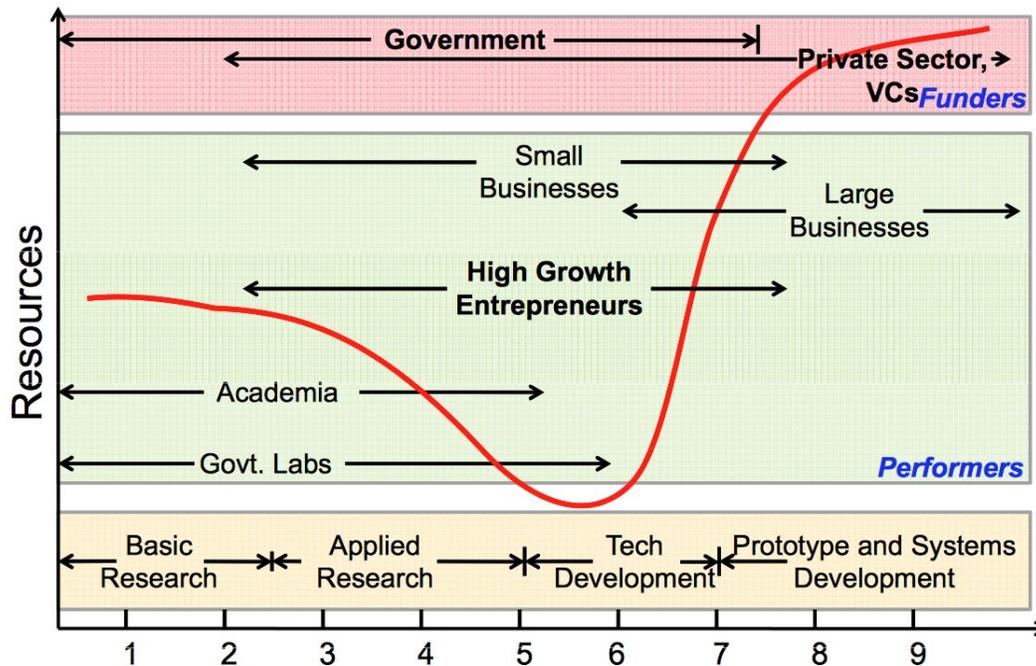


Figure 5-2. Technology Valley of Death

Source: <http://philippleitner.net/technology-readiness-levels-impact-of-science-and-the-valley-of-death/>

After successfully deploying a few demonstration units and initial commercial units, many in the technology development realm consider progress to occur unabated, pulled easily by the demand of the market now that the core technology's future performance has been proven. Unfortunately, this is not the case.

Successfully deploying and operating new technologies is a well-known challenge for groups that own and operate electric power infrastructure like utilities, IPPs, developers, private equity groups, etc. They understand that operators need time to gather operating data to understand both the current costs to operate the units and their performance envelope, and possible future costs and performance capabilities once these lessons have been incorporated back into the OEM and system integrator supply chain, plus additional operating experience to provide a system that can then be integrated into their own operating and maintenance structure. For this reason, capital providers for project development efforts for technologies like energy storage have much in common with VCs trying to fund early-stage technologies and move them to a deployable product stage.

The project development valley of death can thus be seen similarly as the steeply increasing need for investment capital for owners and operators to prove out a successful project cost reduction curve and increasing project performance envelope. Although the sums are much larger, infrastructure-oriented groups like debt providers are typically loath to invest in projects that are not already mature from a project portfolio perspective, leaving the early stage (first 5-10 years) of project deployment to private equity groups willing to take on the higher risk.

The U.S. Department of Energy is well positioned to be an essential player in helping the energy storage project development industry transition to a more mature and less risky status. This effort will take many forms, such as helping the industry to transition from public to private funding,

applying lessons learned from solar and wind project development efforts, and identifying and addressing challenges in the energy storage project development market.

5.6.1. DOE Support: From Public to Private Financing

The U.S Department of Energy has been supporting the development of innovative technologies like energy storage since its inception. In that effort, many new technologies have been developed for use in the market and metrics such as the Technology Readiness Level (TRL) have been developed to track the advancement to commercial status. After the technology development has progressed, early project deployments have also been supported to prove out the performance of commercial level systems. Unfortunately, that has not been sufficient support to widespread commercial adoption of these technologies as the project development process requires significant private capital, and there is a gap between when investors feel that the technology is commercially viable, and when they want to provide significant low-cost capital to expand the number of projects.

This is not a new phenomenon. The National Renewable Energy Laboratory (NREL) developed a report “Bridging the Valley of Death: Transitioning from Public to Private Sector Financing” [NREL/MP-720-34036]⁵² in 2003 to highlight the challenges on the difficulties in the hand-off to private sector investors of publicly funded, early-stage technology investment opportunities in entrepreneurial ventures. The report highlights exploring the financing disconnects between public sector and private sector investors using three perspectives:

1. Divergence of public and private sector values, requirements, and goals
2. The cash flow “valley of death,” and
3. Private sector perspectives on risk

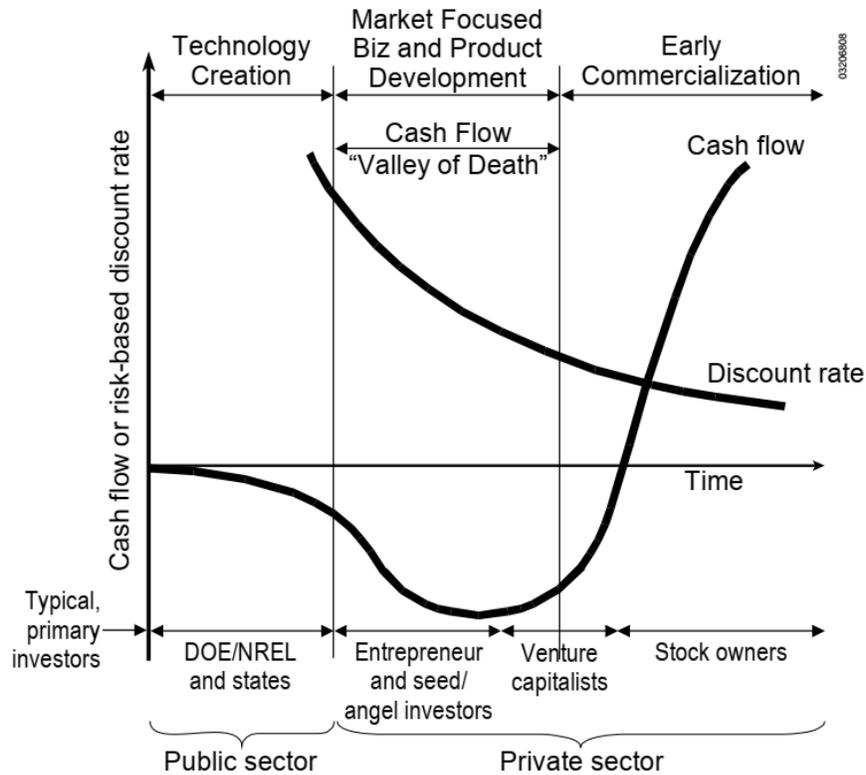


Figure 5-3. The Cash Flow Valley of Death

Source: Bridging the Valley of Death: Transitioning from Public to Private Sector Financing

Each of these perspectives illuminates the nature of the problem in a slightly different manner; however, from these different lenses several common themes emerge that point to a set of remedies that are both straightforward and powerful. These remedies are:

1. Reduce information gaps or asymmetries between the two sectors
2. Foster an accelerated shift from a technology to a market focus
3. Explore and develop novel co-investment partnerships with the private sector

Efforts by the U.S. Department of Energy continue. In particular, the DOE Loan Programs Office (LPO) is designed to support the financing of large-scale energy infrastructure projects in the United States. The LPO highlights⁵³ its offering along three avenues:

- **Access to Capital:** The LPO can provide first-of-a-kind projects and other high-impact, energy-related ventures with access to debt capital that private lenders cannot or will not provide. LPO has approximately \$40 billion in available loan and loan guarantee authority.
- **Flexible Financing:** The LPO can provide financing that meets the specific needs of individual borrowers. LPO can be the sole lender to a project or can co-lend with or guarantee loans from private lenders. Additionally, LPO has capacity to finance large projects as a sole lender or to fill gaps in financing as part of a group of lenders.
- **A Committed Project Partner:** Lenders often prefer to engage with a project when the deal is fully formed; however, LPO encourages early engagement during project development.

LPO can take the time to dive deep and understand the project and its technology. And after loan closing, LPO remains a valuable partner to borrowers throughout the entire loan term.

5.6.2. Prior Government Efforts

The U.S. Department of Energy has previously been a crucial actor in supporting the project development and financing environment of a key renewable energy technologies, especially solar and wind energy technologies.

In both of these efforts, early-stage technology development support has been augmented with additional focus on system integration, soft costs, and project financeability. This has proven very successful in supporting the growth of the industry and is a proven track record for the U.S. Department of Energy to follow with its efforts in energy storage.

There has been some early industry led organizing efforts that have developed initial attempts at early-stage resources that

5.6.2.1. Solar

The U.S. Department of Energy Solar Energy Technologies Office⁵⁴ (SETO) funds solar energy research and development to improve the affordability, performance, and value of solar technologies on the grid. Their efforts are in five key categories.

- **Photovoltaics:** The Solar office supports development of low-cost, high-efficiency photovoltaic (PV) technologies to make solar power more accessible.
- **Concentrating Solar-Thermal Power:** SETO supports CSP research and development to improve the performance, reduce the cost, and improve the lifetime and reliability of CSP technologies.
- **Systems Integration:** Systems integration research in SETO helps advance the reliable, resilient, secure, and affordable integration of solar energy onto the nation's grid.
- **Manufacturing and Competitiveness:** SETO supports solar manufacturing and competitiveness R&D to develop pathways to commercialization for disruptive innovation in the solar industry.
- **Soft Costs:** Soft costs research in SETO addresses challenges associated with non-hardware cost components of a solar energy system.

SETO has also been critical to improving the financeability of solar projects. The U.S. DOE fostered the development of the Solar Access to Public Capital (SAPC) Working Group which was active over a 3-year period between 2012 and 2015 to develop standard residential lease and commercial power purchase agreement (PPA) contracts available for use by solar developers, customers, and third-party finance providers. The SAPC was part of a National Renewable Energy Laboratory (NREL) multi-year project, funded by the U.S. DOE Balance of System Program, which aimed to facilitate and hasten the solar photovoltaic (PV) industry's access to public capital through securitized instruments and other investment vehicles. The project comprised three distinct efforts, each targeting a market barrier to solar securitization: SAPC working group, data collection, and analysis. The results of the effort were designed to improve consumer transparency, reduce transaction costs in the solar contracting process, and facilitate the pooling of associated cash flows so that they may be securitized and sold in the capital markets.

To continue to the development of these valuable contracting tools, the SAPC Working Group reformed into the Solar Energy Finance Association (SEFA). The goal of the SEFA was to advance the availability of public capital and expand the financing options for the solar energy industry. SEFA relied on involvement of stakeholders in the solar industry, banking, government and the capital markets to promote their common interests and to improve financing conditions and availability of financing options for solar energy. The group's flagship initiative involves overseeing the standard lease and power purchase agreements developed by the Solar Access to Public Capital (SAPC) working group.

As the solar industry continued to expand, the need to harmonize efforts and provide higher quality and more capable model contracts to support further growth prompted the SEFA to merge with the Solar Energy Industries Association (SEIA) on Jan 3, 2017. This is a clear example of the natural progression of market model development—an industry continues to evolve, a widely regarded trade group needs to step in to ensure broad agreement and support for continued contract development to maintain growth in the industry that will support all of the current and future market roles. SEIA maintains model leases and PPAs for the industry on its website.

5.6.2.2. Wind

The Department of Energy Wind Energy Technologies Office⁵⁵ invests in energy science research and development activities that enable the innovations needed to advance U.S. wind systems, reduce the cost of electricity, and accelerate the deployment of wind power. The group supports the project development and financing efforts through a number of avenues, including:

- **Wind Resource Characterization and Plant Optimization:** WETO provides wind energy resource characterization for both land- and off-shore offshore wind energy potential deployments. In addition, the Office models the complexity of wind plant atmospheric air flow to better understand the complex dynamics of winds with regards to variable terrain, rotor wakes, and turbulent weather.
- **Wind Component and System Research, Development, and Testing:** WETO supports the development of regional test centers for large scale wind plants, wind turbines, rotor blades, and new drivetrain configurations. The Office also supports efforts to advance small wind turbine by improving the certification framework for these products. Building off all of this work done for on-shore deployments, WETO has been focusing on off-shore deployment challenges.
- **Market Barrier Mitigation:** WETO evaluates the impacts of wind turbine deployment on society and local animal life and determines ways to mitigate the most disruptive of the effects. The office also evaluates a variety of wind integration challenges and promotes the development of best practices development to move the industry forward. Some of the most critical electric power system integration challenges include matching wind production with the needs of the regional power markets electricity supply and demand balance, wind forecasting, wind speed variability, and cyber security. In addition to technical challenges, WETO address economic challenges of wind integration, including wind technology cost, and delivered economic cost of wind energy to the power grid. Finally, WETO developed the WINDEXchange platform which it uses to distribute helpful information about wind energy technology and economics for individuals and communities make better informed decisions about deploying and using wind energy.

5.6.2.3. Energy Storage

Three examples of industry led activity in the energy storage industry showcase the growing level of interest in project development efforts.

The first example is the EPRI-Energy Storage Integration Council (ESIC). According to the Electric Power Research Institute (EPRI), EPRI established the Energy Storage Integration Council (ESIC) in 2013 to advance the deployment and integration of energy storage systems through open, technical collaboration. ESIC facilitates discussion among utilities, storage developers, researchers, regulators, and others, creating a space where stakeholders can collectively identify industry gaps, share deployment experiences, and work together to close those gaps. ESIC convenes and coordinates strategic working groups and action-oriented task forces to publish a set of guidelines and tools to support the safe, cost-effective, reliable, and environmentally responsible deployment of energy storage.

The second example was the Advancing Contracting in Energy Storage (ACES) Working Group. The ACES Working Group was formed in 2018 to document existing energy storage expertise and best practices to improve project development and financing efforts across the energy storage industry. The ACES Working Group was an independent industry led and funded effort founded to develop a best practice guide for the energy storage industry. To help make the Energy Storage Best Practice Guide possible, over 70 different companies and organizations contributed generously to the form of content, counsel, and expertise. Through this combined effort, the ACES Working Group developed a library of educational resources to strengthen the fundamental understanding of energy storage project development for those developing and investing in energy storage projects.

The third example is the various reports from the Energy Storage Association. Three reports showcase the breadth of resources being developed by this leading industry group.

- **U.S. Energy Storage Operational Safety Guidelines⁵⁶.** According to the ESA, the purpose of these Guidelines is to: (1) guide users to current codes and standards that support the safe design and planning, operations, and decommissioning of grid-connected energy storage systems, and (2) present many primary recommendations which can be used in hazard reduction and mitigation. It is not intended to provide an exhaustive list of guidelines for all operational hazards that could arise.
- **Advanced Energy Storage in Integrated Resource Planning (IRP)⁵⁷:** According to the ESA, the report provides an overview on how to appropriately include advanced storage in long-term utility resource planning processes with examples from utilities already doing so. In addition, the report includes a set of up-to-date cost inputs from publicly available sources, a summary of utility IRPs from 2016-2017 that examine energy storage, and a list of recent state regulatory decisions on including storage in IRPs.
- **End-of-Life Management of Lithium-ion Energy Storage Systems⁵⁸:** According to the ESA, this white paper describes the current status of Lithium-ion (Li-ion) battery reuse and recycling opportunities and explains how the energy storage industry may be able to adopt some of the lessons learned from the management of an increasing stock of used electric vehicle (EV) batteries. The paper also outlines various EV and ESS initiatives to improve the management of the Li-ion battery life cycle.

5.6.3. Next Steps for Energy Storage

The U.S. DOE can play a vital role in overcoming the project valley of death for the energy storage industry. Key steps that would incorporate the lessons learned from other industries such as wind and solar where the U.S. DOE played a central role in establishing a foundation of technical knowledge, industry input, and marshalling stakeholder involvement to coordinate efforts across the industry to improve financing capability, lower regulatory hurdles, etc.

Initial key areas of industry effort include engineering, performance, project economics, and codes & standards. Within each area, three levels of resource development would provide a sound foundation for the growth of the market.

- First, identify core hurdles areas for project development for emerging technologies and innovative applications. Essentially, define what we know, and highlight what we do not know.
- Secondly, develop a project development checklist and current best practices to improve the quality of project planning and documentation.
- Finally, establish a continuing focus of effort on the four technical issues, coordinated by the DOE-OE laboratory programs and industry participants to drive development will develop best practices tools and resources of critical project market components and encourage sharing and dissemination of these products industry wide. These will include:

5.6.3.1. Engineering

A firm technical understanding of the capability of the system is essential for successful project development effort. This engineering analysis and evaluation of the technical aspects of the project then forms the basis of determining the economics of the facility, and the financial viability of the project, providing a means to structure an estimate the risk to the projects cashflow. Aspects of the analysis begins at the cell level and moves toward the complete system, focusing on those areas that will have an impact on the financial viability of the system, allowing the owner/operator to ascertain what applications are within the projects capability profile.

Some key areas of engineering analysis include independent engineering reports, bankability studies, interconnection studies, and warranties.

- **Independent Engineering (IE) Reports:** IE Reports are conducted by 3rd party engineering firms for the developers or capital providers to understand the capital cost and technical aspects of the project, contractual obligations (schedule & physical requirements), and market risks stemming from market rules and pricing.
- **Bankability Reports:** Bankability Reports evaluate the OEM's claim of product quality and reliability. These reports are generally used for non-lithium technologies as the base knowledge on the technology or project experience is smaller. These reports provide a deeper view into the technology science and capabilities, manufacturing process, system operation requirements, and market issues that differentiate the technology and its revenue earning potential.
- **Interconnection Study:** An interconnections study ensures that the distributed generating facility's interconnection to the local power grid is properly designed and identifies and allocates costs for any required grid upgrades to ensure a safe and stable interconnection.

Interconnection studies provide project developers and capital providers that the project is able to be connected to the grid

- **Warranty:** Warranties are provided by OEMs for three areas: manufacturing defect, performance, and availability. Each of these coverage areas are typically subject to a specific usage profile: Temperature, C-Rate, cycle count, energy throughput, and state of charge requirements. Warranties provide assurance to project developers and capital providers that the equipment selected for the project is capable of supporting of the intended usage profile.

5.6.3.2. Technical Performance

The technical performance of an energy storage system is central to the ability of the developer to design a profitable design and usage profile for a project, and for the operator to ensure that the system will reliably perform per the requirements of the contracted services. There are a number of fundamental aspects of project performance that require attention. Such issues include standardization of measurements and communication to allow different projects and technologies both from a technical and financial analysis on a full project basis.

Some key areas of technical performance analysis include Performance Measurement, Data Standards, Degradation, and Replenishment.

- **Performance Measurement.** Performance measurement is a critical requirement in order to define how an energy storage system operates. As the most fundamental as the technical performance of the energy storage system. The first step in this process is to clearly define the metrics by which performance is measured.
- **Data Standards.** Data Standards refers to the need to standardize the data elements in reporting so that key performance indicators on different projects can be shared widely without corruption of the descriptive data.
- **Degradation.** Degradation is the reduction in capacity (kWh) of the battery's energy storage capacity over its lifespan. Different energy storage technologies will experience degradation at different rates. Some technologies will show little or no degradation, while others will experience significantly more.
- **Replenishment.** Replenishment is a strategy to ensure the system maintains a sufficient energy capacity rating to support off-take contracts during the facility's lifespan. There are three general replenishment strategies: oversizing, augmentation, and replacement.

5.6.3.3. Project Economics

Evaluating energy storage project economics is essential for stakeholders across the industry to evaluate the cost and benefits of a possible deployment and evaluate the possible returns on the investment by capital providers. Energy storage project has multiple moving parts; including how different market strategies require different equipment selection, how the same equipment selection can support a variety of applications, and how the same equipment selection supporting the sale applications can have different returns depending on how the operator selects the order in which applications are supported. For these and other reasons, having a common project analysis structure that allows developers, EPCs, and capital providers to have a common means to evaluate projects is imperative.

Some key areas of project economics analysis include applications and the project economic model.

- **Applications:** Applications are the various market uses that an energy storage asset can perform. These market roles form the basis of revenue generation, and incorporate a technical requirement, allowing a definition of the equipment needed to provision the service. Historically, these market roles were existing products and services in the power sector. Through taking advantage of the greater performance capability of energy storage assets, a number of them have changed their technical requirements, or new applications have been proposed/passed.
- **Performance Metrics:** Performance metrics allow for the evaluation of both whether the energy storage asset successfully performs the application's technical requirements, but also allows for the ranking of different energy storage assets all performing the same application. In order to accomplish this, an evaluation of the technical requirements of the application are required to determine the level of asset performance when accomplishing the application.
- **Project Economic Model.** The project economic model allows for a structured economic evaluation of the proposed project. Typically structured in a project pro-forma framework, the project economic model (also known as the project financial model) incorporates all of the different costs and revenue streams into the operating life of the project. In this way, the required cost outlays and revenue generation can be seen individually, as well as allowing for different scenarios analysis to evaluate the different possible revenue streams from different market strategies, as well as impact a probability factor to provide better insights into the risk-adjusted return.

5.6.3.4. Codes & Standards

Codes and Standards are critical to the successful development of energy storage projects at all levels of the industry. Codes and Standards impact the design and operational strategy of energy storage projects in a number of ways. First, these rules have a direct impact on the cost of the energy storage project through the requirements of specific equipment to be used, and the labor practices performed during construction. Second, these rules establish the procedures by which safety, performance and reliability are documented and verified. Failing to achieve signoff on these guidelines during construction can cause significant delays in a project achieving the required approvals needed for the facility to begin operation.

Currently, there are two key areas of focus for Codes and Standards in the energy storage market: safety, and reliability and performance.

- **Safety Standards.** Safety standards ensure the safe and successful operation of an energy storage system. Because of the energetic nature of energy storage systems, there has been a concerted effort to establish and expand regulations to protect personnel and equipment during the operation of these systems. As the industry continues to expand to new chemistries, new locations, and new deployments are used, safety rules will need to be maintained and updated.
- **Reliability and Performance Standards.** Reliability and Performance standards ensure the safe interconnection and operation of the energy storage system to the local power grid. Standards for electrical interconnection are changing rapidly at all levels of the power grid as DER, EV integration, and hybrid power facilities emerge into the utility market, affecting market strategies for deployed energy storage systems.

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- [53] <https://www.energy.gov/sites/default/files/2020/05/f74/DOE-LPO-Brochure-May2020.pdf>
- [54] <https://www.energy.gov/eere/solar/solar-energy-technologies-office>
- [55] <https://www.energy.gov/sites/default/files/2021-04/us-wind-industry-federal-incentives-funding-partnership-opportunities-fact-sheet.pdf>
- [56] <https://energystorage.org/thought-leadership/esa-corporate-responsibility-initiative-u-s-energy-storage-operational-safety-guidelines/>

- [57] <https://energystorage.org/thought-leadership/advanced-energy-storage-in-integrated-resource-planning-irp/>
- [58] <https://energystorage.org/thought-leadership/end-of-life-management-of-lithium-ion-energy-storage-systems/>

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APPENDIX A. U.S. DOE ENERGY STORAGE FINANCING RESOURCES

Energy Storage Grand Challenge

- <https://www.energy.gov/energy-storage-grand-challenge/energy-storage-grand-challenge>

Reports

- **Energy Storage Grand Challenge Roadmap:**
<https://www.energy.gov/sites/default/files/2020/12/f81/Energy%20Storage%20Grand%20Challenge%20Roadmap.pdf>
- **Energy Storage Market Report 2020:**
https://www.energy.gov/sites/default/files/2020/12/f81/Energy%20Storage%20Market%20Report%202020_0.pdf
- **2020 Grid Energy Storage Technology Cost and Performance Assessment:**
<https://www.pnnl.gov/sites/default/files/media/file/Final%20-%20ESGC%20Cost%20Performance%20Report%2012-11-2020.pdf>

Funding and Financing for Energy Projects

- Funding & Financing for Energy Projects: <https://energy.gov/funding-financing-energy-projects>
- Federal Financing Facilities Available for Energy Efficiency Upgrades and Clean Energy Deployment:
<https://www.energy.gov/sites/prod/files/2013/08/f2/Federal%20Finance%20Facilities%20Available%20for%20Energy%20Efficiency%20Upgrades%20and%20Clean%20Energy%20Deployment.pdf>
- Federal Financing Programs for Clean Energy:
<https://energy.gov/sites/prod/files/2016/05/f32/Federal%20Financing%20Programs%20for%20Clean%20Energy.pdf>

Loan Programs Office

- <https://energy.gov/funding-financing-energy-projects>

Office of Electricity (OE)

Energy Storage Program

- <https://www.energy.gov/oe/activities/technology-development/energy-storage>
- Fact Sheet: [Energy Storage Program Fact Sheets](#)

Database

- Global U.S. DOE Energy Storage Database: <https://www.energystorageexchange.org/>

Reports

- [Energy Storage System Guide for Compliance with Safety Codes and Standards](#)
- [DOE/EPRI 2015 Electricity Storage Handbook in Collaboration with NRECA](#)

Energy Storage Technology Advancement Partnership (ESTAP)

- The Energy Storage Technology Advancement Partnership (ESTAP) is a federal-state funding and information sharing project, managed by the Clean Energy States Alliance (CESA), which aims to accelerate the deployment of electrical energy storage technologies in the U.S.
<https://www.cesa.org/projects/energy-storage-technology-advancement-partnership/>
- Energy Storage Procurement Guidance Documents for Municipalities:
<http://www.cesa.org/assets/2016-Files/Energy-Storage-Procurement-Guidance-Documents.pdf>
- Commissioning Energy Storage: <http://www.cesa.org/assets/Uploads/ESTAP-Webinar-Slides-5.20.14.pdf>

Fossil Energy (FE)

- <https://netl.doe.gov/coal/crosscutting/energy-storage>

Energy Efficiency and Renewable Energy (EERE)

- State Energy Program: <https://energy.gov/eere/wipo/state-energy-program>

Energy Information Agency (EIA)

Key Reports

- U.S. Battery Storage Market Trends
https://www.eia.gov/analysis/studies/electricity/batterystorage/pdf/battery_storage.pdf

Articles

- <https://www.eia.gov/todayinenergy/detail.php?id=40072>
- <https://www.eia.gov/todayinenergy/detail.php?id=42995>
- <https://www.eia.gov/todayinenergy/detail.php?id=41833>

Sandia National Laboratory (SNL)

Energy Storage Program

- U.S. Department of Energy, Energy Storage Systems
<https://www.sandia.gov/ess-ssl/>
- U.S. Department of Energy, Energy Storage Systems: Publications:
<http://www.sandia.gov/ess/sandia-national-laboratories-publications/>

Energy Storage Valuation Modeling

- QuEST Model, <https://energy.sandia.gov/tag/quest/>

Key Reports

- DOE/EPRI Electricity Storage Handbook with NRECA:
<http://www.sandia.gov/ess/publications/SAND2015-1002.pdf>

- DOE OE Energy Storage Systems Safety Roadmap Focus on Codes and Standards— SAND2017-9147R: <http://www.sandia.gov/energystoragesafety/wp-content/uploads/2017/08/Roadmap-CS-report-August-2017-final.pdf>
- Energy Storage Financing: *A Roadmap for Accelerating Market Growth* <http://www.sandia.gov/ess/publications/SAND2016-8109.pdf>
- Energy Storage Financing: *Performance Impacts on Project Financing*, https://www.sandia.gov/ess-ssl/wp-content/uploads/2018/12/ESF2-MustangPrairie_SAND2018-10110_final.pdf
- DOE OE Energy Storage Systems Safety Roadmap, http://www.sandia.gov/ess/publications/EnergyStorage_safetyroadmap_2017.pdf
- Energy Storage Procurement - Guidance Documents for Municipalities, <http://www.sandia.gov/ess/publications/SAND2016-8544O.pdf>
- Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems, <http://www.sandia.gov/ess/publications/SAND2016-3078R.pdf>
- Methodology to Determine the Technical Performance and Value Proposition for Grid-Scale Energy Storage Systems: A Study for the DOE Energy Storage Systems Program, <http://www.sandia.gov/ess/publications/SAND2012-10639.pdf>

Pacific Northwest National Laboratory (PNNL)

Energy Storage Program

- PNNL Stationary Energy Storage Reports- DOE OE Energy Storage Program, <https://energymaterials.pnnl.gov/esp/reports.stm>

Energy Storage Valuation Modeling

- Energy Storage Optimization Tools <https://availabletechnologies.pnnl.gov/technology.asp?id=413>

Key Reports

- Energy Storage System Safety: Plan Review and Inspection Checklist, <https://energymaterials.pnnl.gov/pdf/PNNL-SA-124486.pdf>
- Measuring and Expressing the Performance of Energy Storage Systems (Presentation) <https://energymaterials.pnnl.gov/pdf/PNNL-SA-118995.pdf>
- Energy Storage System Guide for Compliance with Safety Codes and Standards; <http://www.sandia.gov/ess/publications/SAND2016-5977R.pdf>
- Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems, <https://energymaterials.pnnl.gov/pdf/PNNL-22010Rev2.pdf>
- Overview of Development and Deployment of Codes, Standards and Regulations Affecting Energy Storage System Safety in the United States; http://www.sandia.gov/ess/docs/safety/Codes_101_PNNL_23578.pdf
- Inventory of Safety-related Codes and Standards for Energy Storage Systems with some Experiences related to Approval and Acceptance; <https://energymaterials.pnnl.gov/pdf/PNNL-23618.pdf>

National Renewable Energy Laboratory (NREL)

Renewable Energy Finance

- Renewable Energy Project Finance, <https://financere.nrel.gov/finance/>

Energy Storage Valuation Modeling

- REopt: Renewable Energy Integration & Optimization, <https://reopt.nrel.gov/tool>

Key Reports

- Installed Cost Benchmarks and Deployment Barriers for Residential Solar Photovoltaics with Energy Storage: Q1 2016, <https://www.nrel.gov/docs/fy17osti/67474.pdf>
- Identifying Potential Markets for Behind-the-Meter Battery Energy Storage: A Survey of U.S. Demand Charges, <https://www.nrel.gov/docs/fy17osti/68963.pdf>
- Battery Energy Storage Market: Commercial Scale, Lithium-ion Projects in the U.S., <https://www.nrel.gov/docs/fy17osti/67235.pdf>

Argonne National Laboratory (ANL)

Energy Storage Program

- <https://www.anl.gov/pse/energy-storage>

Joint Center for Energy Storage Research (JCESR)

Energy Storage Program

- <http://www.jcesr.org/>

Idaho National Laboratory (INL)

Energy Storage Program

- Clean Energy & Transportation, <https://at.inl.gov/SitePages/Energy%20Storage.aspx>

Energy Storage Publications

- <https://avt.inl.gov/project-type/advanced-energy-storage-publications>

National Energy Technology Laboratory (NETL)

- <https://netl.doe.gov/coal/crosscutting/energy-storage>

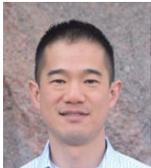
APPENDIX B. 2020 U.S. DOE ENERGY STORAGE FINANCING SUMMIT (VIRTUAL)



Please join us for this event focused on operating experience and how that translates into unit and portfolio strategy, providing greater transparency to financial institutions, and promoting deeper insights into this emerging asset class to facilitate further investment. These studies are part of the U.S. DOE's outreach effort to the financial industry to promote market development through reducing barriers to entry, reducing transaction costs, and promoting wider access to low-cost capital. Speakers will include representatives from the U.S. DOE and industry experts who have experience with the challenges and opportunities of investing in energy storage projects. Speakers will include representatives from the U.S. DOE and industry experts who have experience with the challenges and opportunities of investing in energy storage projects. This complimentary event is by invitation only, and you must be registered to attend; only those people receiving this email directly and registering will be assured a spot while there is space available. Please note that this event is closed to the media.



This year's first keynote speaker is Vice Chair Janea Scott, Commission of the California Energy Commission



This year's second keynote speaker is Eric Hsieh is the Director for Grid Systems and Components at the U.S. Department of Energy.

September 22nd and 23rd, 2020
1:00PM – 4:00PM ET



KIRKLAND & ELLIS LLP

Kirkland & Ellis, LLP
Virtual Event





U.S. DOE ENERGY STORAGE VALUATION WORKSHOP | 10:00 A.M.–1:00 P.M. PDT/1:00–4:00 P.M. EDT

MODERATOR Ray Byrne, *Sandia National Laboratories*

PANELISTS Jan Alam, *Pacific Northwest National Laboratory* Tu Nguyen, *Sandia National Laboratories*
 Giovanni Damato, *Electric Power Research Institute Inc.* Di Wu, *Pacific Northwest National Laboratory*

U.S. DOE ENERGY STORAGE FINANCING SUMMIT | 10:00 A.M.–1:00 P.M. PDT/1:00–4:00 P.M. EDT

CHAIRMAN Richard Baxter, *Mustang Prairie Energy*

DOE ENERGY STORAGE PROGRAM Dr. Imre Gyuk, *U.S. Department of Energy*

WELCOME REMARKS Rohit Chaudhry, *Kirkland & Ellis LLP*

KEYNOTE SPEAKERS Janea Scott, *California Energy Commission*
 Michael Pesin, *Deputy Assistant Secretary, U.S. Department of Energy*

**PANEL 1:
MARKET OUTLOOK**

MODERATOR
 Robert Fleishman, *Kirkland & Ellis LLP*

PANELISTS
 Ryan Franks, *Energy Storage Response Group*
 Jay Goldin, *Munich Re*
 Moe Hajabed, *Aypa*
 Mark Stout, *Viridity Energy Solutions*

**PANEL 2:
CAPITAL PROVIDERS**

MODERATOR
 Brian Greene, *Kirkland & Ellis LLP*

PANELISTS
 Benoit Allehaut, *Capital Dynamics*
 Tim Larrison, *Primergy Solar*
 Patrick Norton, *Javelin Capital*
 Caleb Waugh, *Macquarie Group*

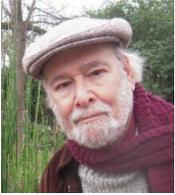
PRESENTED BY:

KIRKLAND & ELLIS



Keynote Speakers

Imre Gyuk, Manager, U.S. DOE Energy Storage Program



Dr. Imre Gyuk is the Energy Storage Program Manager for the U.S. Department of Energy Office of Electricity Delivery and Energy Reliability. He holds a B.S. from Fordham University, and a Ph.D. in Theoretical Particle Physics from Purdue University. He has been responsible for the DOE's energy storage program for 20 years, including directing the \$185 million program for the ARRA stimulus funding.

Janea Scott, Vice Chair, Commissioner, California Energy Commission



Vice Chair Janea A. Scott is serving in her second term on the California Energy Commission. She was appointed Vice Chair in 2019. Scott is one of five commissioners on the Energy Commission, which is the state's primary energy policy and planning agency. Scott was appointed by Governor Edmund G. Brown Jr. in February 2013 and reappointed by Governor Brown in January 2016 to serve as the Energy Commission's public member.

Eric Hsieh, OS DOE Office of Energy



Eric Hsieh is the Director for Grid Systems and Components at the U.S. Department of Energy. His group conducts cutting edge research and development for new grid hardware technologies, including energy storage, robotics, and power electronics.

Host

Rohit Chaudhry, Kirkland & Ellis



Rohit Chaudhry is a debt finance partner in the Washington, D.C., office of Kirkland & Ellis LLP. Rohit's practice focuses on energy and project finance transactions, sales and acquisitions, as well as project restructurings across the energy spectrum, including independent power, oil & gas, midstream and LNG sectors

Summit Chairman

Richard Baxter, President, Mustang Prairie Energy



Richard Baxter is President of Mustang Prairie Energy where he bridges the financial and technical sides of the market. He is the author of the Energy Storage Financing report series for Sandia National Laboratories. He has been active in the energy storage industry for 20 years, and served on the Board of Directors for the Energy Storage Association (ESA), and was Chairman of the Board for NovoCarbon (TSX-V: GLK)

DOE Energy Storage Valuation Workshop

Tu Nguyen, Sandia National Laboratories



Tu A. Nguyen is a Senior Member of the Technical Staff at Sandia National Laboratories. He received his B.S degree in Power Systems from Hanoi University of Science and Technology, Vietnam in 2007. He worked as a Power Transformer Test Engineer in ABB High Voltage Test Department in Vietnam from 2008 to 2009. He received his Ph.D. degree from Missouri University of Science and Technology in December 2014.

Jan Alam, Pacific Northwest National Laboratory



Dr Jan Alam is a power systems engineer at Pacific Northwest National Laboratory (PNNL) where he has been working since October 2016. He is a thrust-area lead within Energy Storage Industry Acceptance program at PNNL, sponsored by U.S. DOE. He is also a key-contributor in PNNL transactive energy systems and grid services valuation domains.

Di Wu, Pacific Northwest National Laboratory



Di Wu is a Senior Research Engineer and a team leader with the Electricity Infrastructure and Buildings Division at Pacific Northwest National Laboratory (PNNL). He received the B.S. and M.S. degrees in electrical engineering from Shanghai Jiao Tong University, China, in 2003 and 2006, respectively, and the Ph.D. in electrical and computer engineering from Iowa State University, Ames, in 2012.

Giovanni Damato, Electric Power Research Institute



Giovanni Damato serves as Principal Project Manager in the Energy Storage and Distributed Energy Resource Program at the Electric Power Research Institute (EPRI). Giovanni has nearly fifteen years of professional experience leading the exploration of distributed energy resources (DER), including grid-connected energy storage. Giovanni provides innovative grid storage and DER techno-economic analyses with strategic recommendations to energy industry stakeholders.

Moderator

Ray Byrne, Sandia National Laboratories



Ray Byrne is manager of the Electric Power System Research department at Sandia National Laboratories, where he has been employed since 1989. He holds a Ph.D. in electrical engineering from the University of New Mexico, an M.S. in electrical engineering from the University of Colorado, Boulder, and a B.S. in electrical engineering from the University of Virginia. He also completed an M.S. in financial mathematics at the University of Chicago. Previously, he was a distinguished member of the technical staff at Sandia.

Panel 1: Markets

Jay Goldin, Munich RE



Jay Goldin is the Vice President of Green Tech Solutions for Munich Re America. In this role, he works with energy system manufacturers, developers and financiers to support solar, wind, energy storage and bioenergy project development. Prior to Munich Re, Jay led business development at Enphase Energy and received his MBA and AB from Stanford University.

Nick Warner, Energy Storage Response Group



Nick Warner's professional career has focused primarily on safety topics related to battery storage integration and fire safety as well as failure analysis of energy storage systems. He has applied his experience in battery testing to supporting battery degradation and performance validation, failure analysis and the evaluation of materials and sensors for passive and active safety applications.

Mark Stout, Viridity Energy Solutions: an Ormat Company



Mark Stout leads Viridity Energy's Western US Business Development team, overseeing origination, environmental permitting, interconnection and acquisitions for utility-scale battery energy storage projects. Prior to Viridity Energy, Mark served in various roles in utility-scale solar PV and energy storage project development.

Moe Hajabed, Aypa



In 2016, Mr. Hajabed founded NRStor C&I, which became the largest behind-the-meter energy storage developer, owner, and operator in Canada. Mr. Hajabed successfully raised multiple rounds of capital from two major investors, led the company's expansion into the U.S., and negotiated a groundbreaking partnership with Honeywell – creating the largest C&I battery storage deployment program in the world, and the first performance guarantee product in the energy storage industry.

Moderator

Bob Fleishman, Sr. Of Counsel, Morrison & Foerster, LLP [Moderator]



Robert Fleishman is senior of counsel in the firm's corporate department, resident in the Washington, D.C. office. Mr. Fleishman has a leading reputation defending energy and financial industry participants and individuals in energy markets against charges of market manipulation, particularly before the Federal Energy Regulatory Commission (FERC), the Commodity Futures Trading Commission (CFTC), and other regulatory bodies, and advising companies on the energy regulatory and compliance aspects of transactions and other energy market activities.

Panel 2: Capital Providers

Patrick Norton, Javelin Capital



Patrick Norton is a Director at Javelin Capital, where he focuses on new deal origination and execution in US renewables, energy storage, energy efficiency, and energy technology. He has more than fourteen years of experience in the energy industry with a background that includes positions in investment banking, renewable energy development, venture capital, and project management.

Caleb Waugh, Macquarie Group



Caleb Waugh is a Vice President at the Macquarie Capital Green Investment Group working on the global energy technology and solutions team. The team focuses on project and equity level investments in grid-scale energy storage, distributed energy resources and electric vehicle charging/mobility.

Tim Larrison, Primergy Solar



Tim is the Chief Financial Officer of Primergy Solar – the North American investment vehicle for Quinbrook Infrastructure Partners in the solar and solar plus energy storage sector. He has 25 years of corporate and project finance experience in the energy, water, and telecommunication sectors. Over the past 14 years he has been the Chief Financial Officer of various businesses including 10 years in the renewable energy sector.

Benoit Allehaut, Capital Dynamics



Benoit is a Managing Director on the Clean Energy Infrastructure (“CEI”) team in New York and sits on both the CEI Investment Committee and Responsible Investment Committee. With over 20 years of energy and infrastructure finance experience, Benoit has become one of the industry’s leading originators. He is also responsible for investment strategy, execution and management.

Moderator

Brian Greene, Kirkland & Ellis



Brian Greene is a debt finance partner in the Washington, D.C., office of Kirkland & Ellis LLP. Brian’s practice focuses on the representation of lenders, private equity funds, institutional investors, and multilateral and bilateral agencies in domestic and international project finance, energy and infrastructure projects, particularly in the United States and Latin America.

Attendee List

First Name	Last Name	Job Title	Company
Ali	Amirali	Senior Vice President	Starwood Energy Group
Ann	Anthony		Key Capture Energy
Julia	Bell	Head of Acquisitions	CleanCapital LLC
Adam	Bernstein	Managing Director	North Sky Capital
Robert	Blair	Head of Asset Management, Renewable Energy	Apple Inc.
Emma	Broderick	Associate	CleanCapital LLC
Raymond	Byrne		Sandia National Laboratories
Helen	Calverley	Senior Manager and Principal Counsel	Apple Inc.
Terry	Cantorna		Pattern Energy Group Inc.
Stella	Cao	Vice President	Rabobank
Babu	Chalamala	Manager	Sandia National Laboratories
Shivam	Chauhan	Analyst	Customized Energy Solutions India Pvt Ltd
Jimmy	Cheung		GE Power
Jason	Cho	Associate	Generate Capital, Inc.
Jae	Choi	Director	Hanwha qcells
Adrian	Clark	CEO	Renstor LLC
Giovanni	Damato		EPRI
Debi Prasad	Dash	Director	Customized Energy Solutions India Pvt Ltd
Sara	Deslierres	Office Manager	Primergy Solar LLC
Ron	DiFelice		Energy Intelligence Partners
Pedro	Elizondo	Senior Manager, Business Development	FlexEnergy
Ruben	Fontes		Ameresco Inc.
Roman	Fontes		Western Area Power Administration
Ryan	Franks		Energy Response Group
Bob	Galyen	Owner	Galyen Energy LLC
Luciano Andres	Garcia Rodriguez	Postdoc	Sandia National Laboratories
Eva	Gardow	Principal Tech Lead	EPRI
Ben	Gionet	Associate	Rabobank
Yaron	Glazer	Partner	Atlas Renewable Development
Dmytro	Glazkov	Senior Energy Specialist	World Bank Ukraine
Alfred	Griffin	President	NY Green Bank
Moe	Hajabed	President	NRStor C&I
Kristian	Hanelt		Clean Power Finance, Inc.
Yazan	Harasis	Co-Founder	Power Edison
Cliff	Henry	President & CEO	Solar USA Power
Claus	Hertel	MD	Rabobank
Cody	Hill	Director, Energy Storage	LS Power Development, LLC
Ken-Ichi	Hino	Director, Energy Storage	Geronimo Energy
Adam	Hise	CEO	Embalance Storage LLC
Eric	Hsieh	Office of Director, EPSA	Department of Energy
Craig	Irwin	Storage Analyst	ROTH Capital Partners
Ty	Jagerson		Malta Inc.
Rory	Jones		Delorean Power LLC
Mark	Juergensen		Cleantech Energy
Michele	Kaufman	Director of Business Development	Customized Energy Solutions
Casey	Keller		Able Grid
Casey	Keller	Managing Member	Virescent Consulting
Andrew	Kessler	Managing Director	NY Green Bank
Sandeep	Kohli	Senior Energy Specialist	The World Bank Group
Krish	Koomar	Chief Financial Officer	esVolta, LP
Joe	Krawczel		Strata Solar
Adam	Larner	COO	Primergy Solar LLC

Attendee List (Cont.)

First Name	Last Name	Job Title	Company
Bryan	Lee		SK E&S Americas
A. Donald	Lepore	Partner and General Counsel	True Green Capital Management LLC
Jie	Li	Analyst	CATL
Martin	Li	Marketing	CATL
Robert	Lydan	Managing Director	Phoventus
Chester	Lyons	Partner	Energy Storage Development Partners
Randy	Mann		EsVolta
Phil	Marlles	Principal	Apollo
David	Mauer	VP, Sales and Services	Renewance
Dave	Mauer	VP Sales and Services	Renewance
Alex	Mayer	Head of Technology	Noria Energy
Hugh	McDermott		ESS
Roger	Miksad	EVP & General Counsel	Battery Council International
Troy	Miller		GE Power
Peter	Möckel	Principal Industry Specialist	International Finance Corporation
Phillip	Monk	Senior Legal Counsel, Energy	Apple Inc.
Olivier	Mussat	Chief Investment Officer	International Finance Corporation
James	Naviaux	Director, Global Partnerships & Commercial Strategy	ESS Technology Inc.
Mark	Nelson	Managing Partner	MarkRLG Capital
David	Nickerson	Director of Business Development	LSIS USA
Koji	Nishida	Senior Energy Specialist	The World Bank Group
Chris	Pagano	Vice President and General Manager	Hitachi Capital America Corp
Alexander	Palese		Riverside Management Group, LLC
Carl	Parker	Chief Technical Officer	Clark Global Energy Corporation
David	Pascualy	Vice President	Ampt, LLC
Howard	Passell		Sandia National Laboratory
Frank	Petrocelli	Senior Risk Analyst	Argo Group US
Ren	Plastina	Managing Director	Crédit Industriel et Commercial
Josef	Pommerening	Green Tech Solutions	Munich Re
Andrzej	Potasinski		US DOE Loan Program Office
Anthony	Price	Director	Swanbarton Limited
John	Ravis	Partner	JGR Advisory Services
James	Richards	Investor	Garuda
Erik	Richardson		EnelX
Joshua	Rogol	Vice President, Energy Storage	Strata Solar
George	Schulz	Vice President	Argo Group US
Danny	Seagraves		Willis Towers Watson
Sven	Semmelmann	Vice President	Generate Capital, Inc.
Rubin	Sidhu	Managing Director	Hareon Solar Technology Co., Ltd.
Brett	Simon		Eos Energy Storage
Matthew	Sparacino	MD	Apollo
Yoshiko	Takeda	Deputy Chief Representative	Kansai Electric Power
Laura	Tamjarv	Associate	CleanCapital LLC
Puneet	Verma	Principal	SER Capital Partners
C	Vickery		GlidePath Power Solutions LLC
Rahul	Walawalkar	President & MD	Customized Energy Solutions India Pvt Ltd
Nick	Warner		Energy Storage Response Group
Russ	Weed		Cleantech Strategies
Melissa	White	CFO	GlidePath Power Solutions LLC
Rick	Winter	President & CEO	UET
Dixon	Wright	Senior Vice President	USI Insurance Services
Vennela	Yadhavi	Business Development Engineer, Renewable Energy	New York Power Authority
Aram	Zamgochian	Senior Director of Strategic Partnerships	ESS Technology Inc.

Synopsis

On September 22nd & 23rd, 2020, Kirkland & Ellis, and Mustang Prairie Energy in partnership with Sandia National Laboratory presented a two-day Energy Storage Finance Advisory Committee Meeting at Kirkland & Ellis' San Francisco that had 150 attendees. Speakers included representatives from the U.S. Department of Energy, the California Energy Commission, and industry experts who have experience with the challenges and opportunities of investing in energy storage projects.

A Link to the recording of the event is found here:

<https://www.kirkland.com/events/kirkland-seminar/2020/09/2020-kirkland-doe-energy-storage-financing-summit>

The Summit was the first Energy Storage Finance Advisory Committee Meeting for a U.S. Department of Energy funded study to evaluate operations and strategies for energy storage systems. This series of studies are part of the U.S. Department of Energy's effort to promote market development through reducing barriers to entry, reducing transaction costs, and promoting wider access to low-cost capital in order to promote development across the energy storage industry.

The event was held over a two-day period, with the first day focused on the U.S. DOE speakers and the valuation workshop. The second day continued with additional Keynotes and panels of market participants.

On day one, the first DOE Keynote was given by Dr. Imre Gyuk of the Office of Electricity of the U.S. Department of Energy. His presentation showcased the efforts of the U.S. DOE to support energy storage technology and market development. The presentation highlighted all of the areas where the U.S. DOE is supporting market analysis and development and showcased how these efforts support other DOE and market efforts. Highlights included emphasis on technical and economic valuation requirements for long duration energy storage, and key demonstration projects with Tribes, Military bases, and utilities.

The final event on day one was the U.S. Department of Energy's Energy Storage Valuation Workshop. This event provided an overview of project valuation model development and insights into the economic valuation development efforts. Parties from Sandia National Laboratories, Pacific Northwest National Laboratory, and the Electric Power Research Institute presented their models and examples of the type of project evaluation capable from the different approaches.

The first Keynote address of day two was provided by Janea Scott, Vice Chair, Commissioner, California Energy Commission. Her presentation showcased the efforts of the State of California's effort to promote the development of energy storage project development at all levels of the electrical power sector to promote customer choice, improved service, and a more resilient power grid. In particular, the CEC highlighted its work with the DOE and how the two groups have complementary roles in the development of emerging technologies.

The second Keynote of day two was provided by Eric Hsieh, Director, Grid Systems and Components at the U.S. Department of Energy's Office of Electricity. His presentation highlighted the efforts and plans of the Energy Storage Grand Challenge, and how the program is designed to highlight and marshal the capabilities of the U.S. Department of Energy to accelerate the

development, commercialization, and utilization of next-generation energy storage technologies and sustain American global leadership in energy storage.

The first panel of the day focused on the Markets for energy storage project development. The discussion focused on the current state of project financing for large scale energy storage projects currently, how the market is changing, and included expectations for where it will go in the next two to three years. Key factors driving the market included the ongoing interest by FERC on energy storage regulation, revenue recognition, the impact of co-located solar/storage facilities, and regional variations based on State level differences in market revenue potential and incentive support. The panelists also shared their insights into the current system integrator competition driving down system costs and how that impacts the number and quality of equipment providers. This is becoming a concern to developers, as although the number and scale of projects are growing, the number of trusted providers of the technology remains a small number. For this reason, strong partnerships with strong and technically capable firms are imperative. Mitigating the risk of project operation as grown in importance to insurers, and thus there has been a heightened focus on safety. EMS software was mentioned as especially critical to ensuring clear visibility of operations. The growing acceptance that fires will continue to raise awareness of adherence to more stringent codes and inspections. Ensuring long-term successful performance of the system matches the dispatch requirements of the off-take agreement is critical to ensure revenue for the project. This revenue will be in both (hopefully) contracted and merchant forms. For this reason, additional sub-markets such as CCA solar projects are seen a viable means for deployment as there has been interest in long-term storage deployments in CA, and hopefully in other states soon as well. Wind hybrid markets were also mentioned as possible applications needing significant storage deployments. Although all agreed that lithium ion (NMC and increasingly LFP) was dominant, significant interest was growing for non-lithium technologies to support longer duration applications. The energy storage market also has many regulatory changes ahead that portends significant change. FERC Order 2222 was mentioned as significantly improving the economics of BTM storage, but at the requirement of a more sophisticated operating strategy to incorporate both BTM and Wholesale strategies. A deeper level of market understanding was considered important as contracts continue to decline in length, with a merchant tail becoming a regular part of the operational assumption for storage facilities in the future.

The second Panel on day two focused on capital providers. In this portion of the event, panelists were able to discuss the current market for investing in energy storage projects, and what issues impact their decisions on whether to invest or not in a project. A number of key project factors influencing their decisions were raised, including energy management software, O&M Contracts, and EPC contracts. Here, the panelists mentioned that although these issues can be complex, they are critical to the successful design and operation of an energy storage project. It was stressed that people need to “sweat the details” on these important aspects of project development, else they will pay for it later. Capital providers continue to evaluate the strengths of the two dominate market deployments for energy storage systems: solar/storage or stand-alone storage. While the search for high-margin applications continues to be a focus of developers, lenders highlight the need to provide debt coverage at a minimum, with equity profitability coming second. Project development continues to be a game of focus on the details. Understanding the right approach while maintaining flexibility in developing and operating so an earlier cost-minimization choice does not end up limiting the value of the facility as the market evolves. Ensuring reliable revenue generation continues to be a critical area of concern for capital providers. Unfortunately, all markets are structured differently, leading to a lack of similarity across the contracted and merchant risks to be reviewed. Finally, the number of new entrants entering the market continues to put downward

pressure on potential returns for lenders. This leaves experienced lenders priced out some markets, leaving these new, low-cost entrants potentially exposed to significant market and contract risk. Panelists continue to believe therefore that is a significant amount of unpriced market risk from balancing the needs to support both of these revenue streams, leading to possible problems for project owners during future turbulent times in the market.

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APPENDIX C. 2021 U.S. DOE ENERGY STORAGE FINANCING SUMMIT (VIRTUAL)



Please join us for this event focused on operating experience and how that translates into unit and portfolio strategy, providing greater transparency to financial institutions, and promoting deeper insights into this emerging asset class to facilitate further investment.

These studies are part of the U.S. DOE's outreach effort to the financial industry to promote market development through reducing barriers to entry, reducing transaction costs, and promoting wider access to low-cost capital. Speakers will include representatives from the U.S. DOE and industry experts who have experience with the challenges and opportunities of investing in energy storage projects. Speakers will include representatives from the U.S. DOE and industry experts who have experience with the challenges and opportunities of investing in energy storage projects. This complimentary event is by invitation only, and you must be registered to attend; only those people receiving this email directly and registering will be assured a spot while there is space available. Please note that this event is closed to the media.



This year's first keynote speaker is Chandrasekar Govindarajalu, World Bank



This year's second keynote is Alfred Griffin, President, NY Green Bank

Tuesday, January 26th & 27th, 2021
1:00PM – 4:00PM

Kirkland & Ellis, LLP
Virtual Event



KIRKLAND & ELLIS LLP





U.S. DOE ENERGY STORAGE VALUATION WORKSHOP | JANUARY 26 | 1:00–3:00 P.M. EDT

MODERATOR Ray Byrne, *Sandia National Laboratories*

PANEL I Jan Alam, *Pacific Northwest National Laboratory*
 Giovanni Damato, *Electric Power Research Institute Inc.*

Tu Nguyen, *Sandia National Laboratories*
 Di Wu, *Pacific Northwest National Laboratory*

U.S. DOE ENERGY STORAGE FINANCING SUMMIT | JANUARY 27 | 1:00–4:00 P.M. EDT

CHAIRMAN Richard Baxter, *Mustang Prairie Energy*

DOE ENERGY STORAGE PROGRAM Dr. Imre Gyuk, *U.S. Department of Energy*

WELCOME REMARKS Rohit Chaudhry, *Kirkland & Ellis LLP*

KEYNOTE SPEAKERS Alicia Barton, *NY State Energy Research and Development Authority (NYSERDA)*
 Chandrasekar Govindarajalu, *World Bank*

**PANEL 1:
 MARKET OUTLOOK**

MODERATOR Robert Fleishman, *Kirkland & Ellis LLP*

PANELISTS Ryan Franks, *Energy Storage Response Group*
 Jay Goldin, *Munich Re*
 Moe Hajabed, *Aypa*
 Mark Stout, *Viridity Energy Solutions*

**PANEL 2:
 CAPITAL PROVIDERS**

MODERATOR Brian Greene, *Kirkland & Ellis LLP*

PANELISTS Benoit Allehaut, *Capital Dynamics*
 Tim Larrison, *Primergy Solar*
 Patrick Norton, *Javelin Capital*
 Caleb Waugh, *Macquarie Group*

PRESENTED BY: **KIRKLAND & ELLIS**

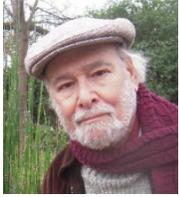


IN PARTNERSHIP WITH:  **Sandia National Laboratories**

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Keynote Speakers

Imre Gyuk, Manager, U.S. DOE Energy Storage Program



Dr. Imre Gyuk is the Energy Storage Program Manager for the U.S. Department of Energy Office of Electricity Delivery and Energy Reliability. He holds a B.S. from Fordham University, and a Ph.D. in Theoretical Particle Physics from Purdue University. He has been responsible for the DOE's energy storage program for 20 years.

Chandrasekar Govindarajalu, World Bank



Chandra Govindarajalu leads the global battery storage program at the World Bank. The World Bank has made commitment to accelerate deployment of battery storage in the developing world with an aim to finance 17.5 GWh of new battery storage in developing countries by 2025. He also leads the energy climate finance team which is responsible for mobilizing climate finance from Climate Investment Funds (CIFs), and the Green Climate Funds (GCF).

Alfred Griffin, the NY Green Bank



Alfred Griffin is an industry leader in developing innovative solutions in support of the financing of renewable energy generation and energy efficiency projects, and brings 25 years of experience in banking and finance to NY Green Bank.

Host

Rohit Chaudhry, Kirkland & Ellis



Robert Rohit Chaudhry is a debt finance partner in the Washington, D.C., office of Kirkland & Ellis LLP. Rohit's practice focuses on energy and project finance transactions, sales and acquisitions, as well as project restructurings across the energy spectrum, including independent power, oil & gas, midstream and LNG sectors.

Summit Chairman

Richard Baxter, President, Mustang Prairie Energy



Richard Baxter is President of Mustang Prairie Energy where he bridges the financial and technical sides of the market. He is the author of the book "*Energy Storage: A Nontechnical Guide*" (PennWell), and author of the Energy Storage Financing report series for Sandia National Laboratories. He has been active in the energy storage industry for 20 years, and served on the Board of Directors for the Energy Storage Association (ESA), and was Chairman of the Board for NovoCarbon (TSX-V: GLK)

DOE Energy Storage Valuation Workshop

Rodrigo Trevizan, Sandia National Laboratories



Rodrigo D. Trevizan is a Senior Member of Technical Staff at Sandia National Laboratories. Rodrigo authored research papers on the subjects of control of energy storage systems and demand response for power grid stabilization, power system state estimation, and detection of nontechnical losses in distribution systems.

Jan Alan, Pacific Northwest National Laboratory



Dr Jan Alan is a power systems engineer at Pacific Northwest National Laboratory (PNNL) where he has been working since October 2016. He is a thrust-area lead within Energy Storage Industry Acceptance program at PNNL, sponsored by U.S. DOE. He is also a key-contributor in PNNL transactive energy systems and grid services valuation domains.

Di Wu, Pacific Northwest National Laboratories



Di Wu is a Senior Research Engineer and a team leader with the Electricity Infrastructure and Buildings Division at Pacific Northwest National Laboratory (PNNL). He received the B.S. and M.S. degrees in electrical engineering from Shanghai Jiao Tong University, China, in 2003 and 2006, respectively, and the Ph.D. in electrical and computer engineering from Iowa State University, Ames, in 2012.

Giovanni Damato, Electric Power Research Institute



Giovanni Damato serves as Principal Project Manager in the Energy Storage and Distributed Energy Resource Program at the Electric Power Research Institute (EPRI). Giovanni has nearly fifteen years of professional experience leading the exploration of distributed energy resources (DER), including grid-connected energy storage. Giovanni provides innovative grid storage and DER techno-economic analyses with strategic recommendations to energy industry stakeholders.

Moderator

Babu Chalamala, Sandia National Laboratories



Dr. Babu Chalamala is Manager of the Energy Storage Technology and Systems Department at Sandia National Laboratories. Prior to joining Sandia in August 2015, he was a Corporate Fellow at SunEdison (formerly MEMC Electronic Materials) for five years, where he led R&D and product development in grid scale energy storage. Earlier, as a research staff member at Motorola, Research Triangle Institute, and Texas Instruments.

Panel 1: Market Outlook

Troy Miller, GE Renewable Energy



Troy Miller is the North American Sales Leader for Energy Storage at GE Power. He has over 25 years of experience in the Power Engineering industry. Mr. Miller has lengthy experience in the application and implementation of all aspects of energy storage, renewable energy, and microgrids. Mr. Miller is the Chairman of the Board of Directors at the Energy Storage Association (ESA).

Davion Hill, Momentum Energy Partners



Dr. Davion Hill is an entrepreneur, thought leader, deposed and qualified expert witness, and advisor in the energy storage industry. As cofounder of Momentum Energy Storage Partners, he has developed and raised capital for over 90 MW solar and energy storage projects. He previously managed DNV GL's energy storage business in the US and globally.

George Schulz, Argo Group



George has over 20 years' experience in financial services, insurance, product development, underwriting and structuring risk management solutions for the capital markets, he is the market leader for North America at Ariel Re, Lloyd's of London, Clean Energy team.

Kelly Sarber, Strategic Management Group



Kelly Sarber leads the Strategic Management Group and is an expert in sourcing opportunities and building enterprise value around companies and projects in the renewable energy industries. Sarber is currently sourcing utility scale battery project sites in New York and California using a market advantage honed over many decades working with major utilities, solid waste companies and other heavy industrial centric businesses.

Jaya Bajpai, Lockheed Martin Energy



Jaya Bajpai is Head of Analytics in Lockheed Martin's Energy business, focused on energy storage. Prior to Lockheed, Mr. Bajpai focused on enterprise risk, analytics and policy issues in the CEO Office at Seattle City Light, a \$1.4 billion public utility.

Moderator

Bob Fleishman, Sr. Of Counsel, Morrison & Foerster, LLP



Robert Fleishman is senior of counsel in the firm's corporate department, resident in the Washington, D.C. office. Mr. Fleishman has a leading reputation defending energy and financial industry participants and individuals in energy markets against charges of market manipulation, particularly before the FERC, CFTC, and other regulatory bodies, and advising companies on the energy regulatory and compliance aspects of transactions and other energy market activities.

Panel 2: Capital Providers

Jeff Bishop, Key Capture Energy



As co-founder and CEO, Jeff Bishop oversees all aspects of Key Capture Energy and has grown the company from a concept in 2016 to a market leader in building large-scale energy storage projects. He primarily focuses his attention on capital fundraising and allocation, commercial and regulatory strategy, and building a best-in-class team of energy professionals.

Ali Amirali, Starwood Energy Group



Ali Amirali is a Senior Vice President of Starwood Energy Group. In this role, Mr. Amirali is responsible for the expansion of Starwood Energy Group's StarTrans high-voltage transmission assets. He also supports the origination, development and acquisition activities associated with utility-scale power generation and storage projects.

Claus Hertel, Rabobank



Claus Hertel joined Rabobank in 2019 and is a Managing Director in the Project Finance Americas team based in New York. Claus has over 20 years of international banking experience and has been active throughout his career in the origination, structuring and transaction execution of complex structured and project financings.

Gerard Reid, Alexa Capital



Gerard Reid is a Co-founder and Partner at Alexa Capital. He has spent over fifteen years working in investment banking (equity research, fund management and corporate finance) with a focus on both the energy transition and the digital energy revolution the sector is going through. Prior to founding Alexa Capital, he was Managing Director and Head of European Cleantech Research at Jefferies & Co.

Moderator

Brian Greene, Kirkland & Ellis LLP



Brian Greene is a debt finance partner in the Washington, D.C., office of Kirkland & Ellis LLP. Brian's practice focuses on the representation of lenders, private equity funds, institutional investors, and multilateral and bilateral agencies in domestic and international project finance, energy and infrastructure projects, particularly in the United States and Latin America.

Attendee List

	First Name	Last Name	Job Title	Company
1	Jason	Abiecunas	Director	Clean Energy Associates
2	Farhana	Ahmed	Credit Analyst	UBS Investment Bank
3	Doug	Akerson	Senior Vice President	Munich Reinsurance America, Inc.
4	Taylor	Atwood	Senior Director	Alvarez & Marsal
5	Nicholas	Babikian	Business Development	Hunt Energy
6	Sylvia	Barnes	Principal	Tanda Resources LLC
7	Emily	Basham	Senior Manager	CT GreenBank
8	Sean	Becker	President	Sparkplug Power
9	Michael	Belling	Producer	McGriff
10	Tray	Black	Chief Financial Officer and Vice President, Finance	Springbok Energy Partners, LLC
11	James	Brown	Director	Key Capture Energy
12	Jake	Brown	CEO - Launch Tech Energy	Launchtech Holdings
13	Andres	Brugmann	Country Manager	Fieldwood Energy LLC
14	David	Burr	Program Manager	Hitachi Capital America Corp
15	Terry	Cantorna	Business Development Manager, Energy Storage	Pattern Energy Group Inc.
16	Christina	Cazares	Director, Energy Storage	RWE Renewables Americas LLC
17	Chris	Chaffin	Managing Partner	Chaffin Geoscience
18	Hadrien	Chain	Vice President	BBVA Compass Bancshares, Inc.
19	Marc	Chupka	Vice President, Research & Programs	Energy Storage Association
20	Emily	Clark	Credit Officer	CoBank ACB
21	Bruce	Cole	Sr Vice President	Deka Batteries
22	Mark	Coles	Managing Director	Jade Invest
23	Christopher	Conoscenti	Chief Executive Officer	Desert Peak Minerals
24	Carolyn	Conway	Associate	NY Green Bank
25	John	Cooper	Director, Commercial Transactions	Invenery LLC
26	Richard	Corbin	President	Seal Rock Group LLC
27	Tom	Cuffaro	Vice President, Managing Director of Finance	Caithness Energy, LLC
28	Scott	Daniels		Powin Energy
29	Sarah	Davidson	Senior Associate, External Affairs	NY Green Bank
30	Everett	Davis	Finance Manager	Cureton Midstream, LLC
31	Fernando	De Sisternes	Energy Specialist	World Bank
32	Phil	Denara		Key Capture Energy
33	Thomas	Dickson	Chief Executive Officer	New Energy Risk
34	Ron	DiFelice	Managing Partner	Energy Intelligence Partners
35	Patrick	Donahoe	Consultant	DONAHOE@GMAIL
36	Daniel	Dus	Head of Renewables, North America	Adani Group
37	Erica	Egan	Senior Vice President	Helaba Landesbank Hessen-Thüringen
38	Pedro	Elizondo	Senior Technical Manager	Flex LTD.
39	Brett	Feldman	Research Director	Guidehouse
40	Curtis	Flood	Managing Director	Evercore Inc.
41	Kevin	Fok	Director, Operations	LG Chem
42	Albie	Fong	Director of Procurement	Idemitsu Renewables
43	Roman	Fontes	Senior Investment Officer	Western Area Power Administration
44	Ryan	Franks	Business Director	Energy Storage Response Group, LLC
45	William	Franks	Chief Executive Officer and Chairman	IPRE LLC
46	Ross	Gage	Director of Investor Relations	Black Mountain
47	Bryan	Garcia	President and CEO	CT GreenBank
48	Eva	Gardow	Principal Tech Lead	EPRI
49	Robert	Gee	President	Gee Strategies Group, LLC
50	Slavena	Georgieva	Energy Consultant	The World Bank Group
51	Harris	Ghozali	Managing Director	Lazard
52	Yaron	Glazer	VP, North America Energy Storage Development	Ecoplexus, Inc.
53	Jay	Goldin	Vice President	Munich Reinsurance America, Inc.
54	Jim	Greenberger	Executive Director	NAATBatt International (NAATBatt)
55	Daren	Gretz	Senior Vice President	Aon
56	Douglas	Groat	Director	Varde Partners
57	Nitin	Gupta	Senior Vice President	Broad Reach Power
58	William	Hanley	Manager, Project Finance	Stem, Inc.
59	Jennifer	Hanners	Principal	The Blackstone Group
60	Adam	Heath	Director of Finance	Caithness Energy, LLC
61	Samuel	Heller	Vice President	Intrepid Financial Partners
62	Stephen	Hendrickson	Program Manager	U.S. Department of Energy
63	Tuukka	Hess	Senior Counsel	Generate Capital, Inc.
64	Marion	Hill	SVP, Renewable Advisory North America	DNV GL
65	Cameron	Hinojosa	Vice President	The Huntington National Bank, Inc.

Attendee List (Cont.)

	First Name	Last Name	Job Title	Company
66	Andy	Hixson	Project Manager	Redeux Energy Partners LLC
67	John	Howes	Principal	Redland Energy Group
68	Gregory	Hutton	Head of Project Finance, Americas	Rabobank
69	Frank	Jakob	Technology Manager - Energy Storage	Black & Veatch Corp.
70	Dave	James	Managing Director	CoBank ACB
71	Emma	Johnson	Manager, Market Analysis	Key Capture Energy
72	Paul	Jordan	Senior Director	FTI Consulting, Inc.
73	Mark	Juergensen	Managing Director	Cleantech Energy
74	Paul	Jun	Executive Director	SMBC Nikko Securities America, Inc.
75	Sven	Kaludzinski	Attorney	Clean Energy Counsel, LLP
76	Donald	Karner	President	Electric Applications
77	Michele	Kaufman	Director of Business Development	Customized Energy Solutions
78	Dale	Keairns	Specialist Master	Deloitte Consulting LLP
79	Peter	Knowles	Managing Director	
80	Matt	Koenig	Principal Consultant, Business Development	DNV GL
81	Ed	Kranich	Manager, Incentive Programs	CT GreenBank
82	Bradley	Kraus	Senior Vice President	Sunflower Bank, N.A.
83	Joseph	Krawczel	Assistant General Counsel	Strata Solar, LLC
84	Pramod	Kulkarni	Senior Advisor	Customized Energy Solutions
85	Kent	Laber	Chief Financial Officer	TAKKION
86	Paul	LaCourciere	Attorney	Clean Energy Counsel, LLP
87	Akshay	Ladwa	Vice President, Energy Storage and Integration	Brightnight Energy
88	Bonnie	Lamond	Regulation and Policy Manager	Highview Power
89	Chris	Larsen		Dynapower Company
90	David	Latham	General Counsel	Accelerate Resources Holdings, LLC
91	Chris	Lazinski	Commercial Energy Storage Intern	Baywa Re
92	Patrick	Leibach	Deputy General Counsel	Cypress Creek Renewables, LLC
93	Gregory	Lennon	Director of New Business Development	Mitsui & Company Ltd.
94	Emily	Leung	Vice President, Future Mobility and Electrification	BP America, Inc.
95	Rob	Logan	SVP	Mcgriff Energy Constructions
96	Benjamin	Lowe	Project Manager	Roland Berger Strategy Consultants GmbH
97	Matt	Lucas	Managing Director, Business Development	New Energy Risk
98	Chester	Lyons	Partner	Energy Storage Development Partners
99	Miranda	Marjorie		Honeywell International Inc.
100	Zac	Marsalis	Managing Director	Evercore Inc.
101	David	Mauer	Vice President, Sales and Services	Renewance
102	Edward	May	Managing Partner	Energy Intelligence Partners
103	Christopher	McBay	Vice President and Assistant General Counsel	Hunt Consolidated Inc.
104	Ken	McCauley	Executive VP- Energy Storage Services	Turtle & Hughes
105	Rob	McCeney	Partner	PricewaterhouseCoopers LLP
106	Aaron	McCreary	Climate Fintech Lead	New Energy Nexus
107	Hugh	McDermott	SVP Business Development and Sales	ESS Inc.
108	Chris	McKay	Director of Sales - BESS	WEG
109	Michael	McNeley	Project Development Manager	Galehead Development
110	Rafia	Merchant	Manager, Project Finance	NYP&A
111	Lucas	Michelini	Director, Finance	GlidePath Power Solutions LLC
112	Matt	Miller	Co-Founder and Managing Director	Grey Rock Energy Partners
113	Jonathan	Milley		Malta
114	David	Mintzer	President and Chief Executive Officer	Starboard Energy Advisors
115	Peter	Möckel	Principal Industry Specialist	International Finance Corporation
116	Vasilis	Mouratoff	Co-Founder, Chief Financial Officer and General Counsel	Haymaker Minerals & Royalties, LLC
117	Peter	Muhoro	Vice President, Strategic Industry Research and Analysis	Rappahannock Electric Cooperative
118	David	Nickerson	Director of Business Development	LS Energy Solutions
119	Mike	Nolan	Director - Renewables and Energy Storage	IHS Markit
120	Emily	Norkus	Regional Account Representative	Enercon Services, Inc
121	John	O'Brien	Director	Siemens AG
122	Dave	O'Keefe	Assistant Treasurer	Centrus Energy Corp.
123	Roberto	Orendain Berron	Business Analyst	Zinc8 Energy Solutions
124	Luis	Ortiz		Anbaric
125	Bradley	Oswald	Chief Financial Officer	Waterfield Midstream, LLC
126	Chris	Pagano	VP and General Manager of Structured Finance	Hitachi Capital America Corp
127	Darryl	Parker	Vice President, Sales and Marketing	Ampt, LLC
128	Jeffrey	Perry	President and Chief Executive Officer	New England Battery Storage
129	Frank	Petrocelli	Senior Risk Analyst	Argo Group International Holdings Ltd.
130	Ren	Plastina	Managing Director	Crédit Industriel et Commercial

Attendee List (Cont.)

	First Name	Last Name	Job Title	Company
131	Josef	Pommerening	Business Development Manager	Munich Reinsurance America, Inc.
132	Andrzej	Potasinski	Senior Investment Officer	U.S. Department of Energy
133	Ben	Price	Director and Assistant General Counsel	ORIX Corporation USA
134	Sara	Pyne	Manager	CT GreenBank
135	Matthew	Raiford	Technical Manager	Consortium for Battery Innovation
136	Annie	Ratanasim	Sustainability Director	DC Green Bank
137	Fleming	Ray	Senior Project Manager	DNV GL
138	Clinton	Roeder	Executive Vice President and Chief Financial Officer	PrimeFlight Aviation Services
139	Rex	Roehl	Project Development Director	Beacon Power, LLC
140	Christopher	Romani	CEO	Launchtech Holdings
141	Peter	Rood	Chief Development Officer	GlidePath Power Solutions LLC
142	Nicholas	Rossi	Vice President, M&A	Credit Suisse LLC
143	Ingrid	Rousseau		GM
144	Emma	Saavedra	Associate	CT GreenBank
145	Robert	Salandra	Managing Director and Head of Oil and Gas	Whitehall & Company LLC
146	Jonathan	Sampson	Analyst	Quanta Services
147	Pat	Sapinsley	Managing Director, Cleantech Initiatives	Urban Future Lab
148	Matthew	Schilling	Head of Sales	EnerKnol
149	Hendrik	Schroeder	Senior Finance Manager	Raisa Energy LLC
150	George	Schulz	Vice President	Argo Group US
151	Nathanial	Scott	International Business Development Manager	Noble Energy, Inc.
152	Danny	Seagraves	Vice President	Willis Towers Watson
153	Kate	Sherwood	Business Director, Energy Storage Solutions	Wärtsilä
154	Benjamin	Shrager	General Engineer	U.S. Department of Energy
155	Vinod	Siberry	Engineer	U.S. Department of Energy
156	Diane-Charlotte	Simon	Associate	Crédit Agricole Corporate and Investment Bank
157	Harry	Singh	Vice President	Goldman, Sachs & Co.
158	Grace Meade	Sipp	Strategy, Impact, and Investor Relations Intern	NY Green Bank
159	Paul	Smerchanski	Director	Digis Energy
160	Theresa	Smolen	Sr. Communications Manager	NYSERDA
161	Natalia	Soares	Senior Accountant	
162	Bill	Sproull	VP Sales	ESS Inc.
163	Jim	Stover	CMO	VRB Energy
164	Cherian	Thomas	Senior Director	Norddeutsche Landesbank Girozentrale (NORD/LB)
165	John	Thomas		
166	Terence	Thorn	President	JKM Consulting
167	Alexandre	Tilmant	Founding Partner	Tela Energy
168	Baker	Tilney	Vice President	Encino Energy, LLC
169	David	Tine	New Product Development, Energy	Hartford Steam Boiler
170	Anne	Torricelli	Senior Manager	Honeywell International Inc.
171	Trevor	Turbidy	President and Chief Executive Officer	Drylet, LLC
172	Joel	Turkheimer		Key Capture Energy
173	Rick	Ulam	VP of Sales Grid Edge Solutions	Hitachi Powergrids
174	Nick	Van Drimmelen		CTC Strategies
175	Brenda L	Van Etten	GIS specialist	Key Capture Energy
176	Justin	Vaughn	Chief Financial Officer	Peak Energy
177	Rahul	Walawalkar	President & MD	Customized Energy Solutions India Pvt Ltd
178	Michael	Walsh	President and Chief Executive Officer	Canyon Midstream Partners, LLC
179	Tom	Waters	Director	Hitachi Capital America Corp
180	Elizabeth	Waters	Managing Director, Project Finance, Americas	MUFG Union Bank, N.A.
181	Russ	Weed	Independent Consultant	ARES
182	Melissa	White	CFO	GlidePath Power Solutions LLC
183	Rick	Winter	President & CEO	UET
184	Matthew	Wladyka		AT Chem
185	Dixon	Wright	Senior Vice President	USI Insurance Services
186	Vennela	Yadhathi	Business Development Engineer, Renewable Energy	New York Power Authority
187	Aram	Zamgochian	Senior Director of Strategic Partnerships	ESS Inc.
188	Chao	Zhang	Senior Consultant	FTI Consulting, Inc.
189	Jie	Zheng	Managing Director	5P Capital Management
190	Jason	Zilewicz	Vice President	The Huntington National Bank, Inc.

Synopsis

On January 26th & 27th, 2021, Kirkland & Ellis, and Mustang Prairie Energy in partnership with Sandia National Laboratory presented a virtual two-day Energy Storage Finance Advisory Committee Meeting with 300 attendees. Speakers included representatives from the U.S. Department of Energy, the World Bank, and the NY Green Bank, a component of the New York State Energy Research and Development Authority (NYSERDA), and industry experts who have experience with the challenges and opportunities of investing in energy storage projects.

A Link to the recording of the event is found here:

<https://www.kirkland.com/events/kirkland-seminar/2021/01/2021-us-doe-energy-storage-financing-summit>

This event was the second Energy Storage Finance Advisory Committee Meeting for a U.S. Department of Energy funded study to issues and challenges surrounding operations and strategy for energy storage project finance. This series of studies are part of the U.S. Department of Energy's effort to promote market development through reducing barriers to entry, reducing transaction costs, and promoting wider access to low-cost capital in order to promote development across the energy storage industry.

The first day highlighted efforts by the U.S. Department of Energy with two keynote presentations provided. The first DOE Keynote was given by Dr. Imre Gyuk of the Office of Electricity of the U.S. Department of Energy. His presentation showcased the efforts of the U.S. DOE to support energy storage technology and market development. The U.S. Department of Energy's Office of Electricity has been active in the Energy Storage industry for over 20 years. It coordinates its activity with a variety of National Laboratories, including Sandia National Laboratories (SNL), Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL), Argonne National Laboratory (ANL), and Los Alamos National Laboratory (LANL). The presentation highlighted all of the areas where the U.S. DOE Office of Electricity is supporting the market and showcased how all of the different parts support the Departments other efforts. In particular were the U.S. DOE funded pilot projects to prove out innovative technology and showcase valuation analysis to reduce investment hesitancy by the capital markets. Recent activity towards this effort have included H2 storage and long duration energy storage for a variety of system level impacts. Significant interest also highlighted the connection of the Office of Electricity's efforts towards supporting manufacturing of energy storage technologies.

The second DOE keynote was provided by Eric Hsieh, Director, Grid Systems and Components at the U.S. Department of Energy's Office of Electricity. His presentation highlighted the efforts and plans of the Energy Storage Grand Challenge, and how the program is designed to highlight and marshal the capabilities of the U.S. Department of Energy to accelerate the development, commercialization, and utilization of next-generation energy storage technologies and sustain American global leadership in energy storage. The presentation highlighted the trouble with accurate long-term forecasts, and how when evaluating use cases for customers, there are a number of important factors with external independent drivers, each of which can greatly impact the trajectory of the forecast in questions.

Following the Keynotes, the U.S. Department of Energy's Energy Storage Valuation Workshop was held to provide an overview of project valuation model development. Parties from Sandia National

Laboratories, Pacific Northwest National Laboratory, and the Electric Power Research Institute presented their models and examples of the type of project evaluation capable from the different approaches. Attendees were very interested in the assumptions in the different models; of specific interest were details in degradation and augmentation analysis and how different use cases impact revenue stacking strategies.

The second day highlighted efforts by industry participants and contained two keynotes. The first Keynote address was given by Chandra Govindarajalu, who leads the global battery storage program at the World Bank. Govindarajalu's presentation showcased the efforts of the World Bank's new \$1 Billion funding to promote energy storage system globally. This investment capital is accelerating the overall development of energy storage globally, already representing 17.5 GWh through 2025. The World Bank has a growing track record of working with developers, including early with early-stage technologies. This track record has given the World Bank some critical experience developing projects in the emerging market. For many of these projects, sufficient grid planning is essential as many times the existing power grid is tenuous with strong load growth. Beyond technical issues, the World Bank also must deal with a number of macroeconomic factors such as the debt load of the Country.

The second Keynote address was given by Alfred Griffin of the NY Green Bank, a division of the New York State Energy Research and Development Authority (NYSERDA). Griffin's presentation highlighted the long efforts NYSERDA has undertaken to support energy storage technology and project development and highlighted many of the success stories of energy storage development in New York State. Beyond doing projects directly, NYSERDA works with other parts of the NY State government supporting companies and customers in the energy market. This includes adding manufacturing of new and innovative technologies in the State, as well as looking to support customers in their use of energy.

The first panel of the day focused on Markets.

The discussion centered on the current state of project financing for large scale energy storage projects currently, how the market is changing, and included expectations for where it will go in the next two to three years. It was noted that a more volatile market can be far more lucrative for an energy storage facility; opportunity value is more important than commodity value. Obtaining contracted revenue is an important part of minimizing the revenue risk. Some panelists noted that the market is outpacing regulatory structure, there needs to be additional market revenue products for energy storage systems to sell into. Some panelists suggested that a number of other ISO products would be beneficial for the market, and storage would be well suited to provide them, including ramping, super peak capacity, and imbalance reserves.

Hybridizing existing power facilities (typically thermal) was seen as a good opportunity for energy storage systems. These systems extend existing asset lives and provides greater flexibility and optionality to the new combined system. Areas like CA ISO are developing rules that are friendly to hybrid power systems. This strategy is an important one as power markets are changing, with many fossil fuel power plants that were once baseload now being relegated to mid-merit or event peaking—significantly impacting their economic performance. Incorporating energy storage assets to make them a hybrid facility would allow them to extend their operating lifespan through adding additional revenue streams. Even solar projects can benefit from hybridizing by providing more than just provisioning the PPA, such as ancillary services.

There were a number of areas of concern regarding project developers. The level of interest in energy storage continues to grow, and many on the panel see many project developers taking on

additional risk; managing that risk properly is seen the key to success for these players. With the growth of the stationary energy storage market, many panelists highlighted the need for better domestic sourcing choices for energy storage systems. With so few sources available, project developers find it difficult and expensive to find adequate, reliable, and flexible suppliers. Energy Management Systems was also widely acknowledged as critically important as it is a key factor in wholesale project profitability and also allowing commercial and industrial assets to be promoted for wholesale applications is formal ISO markets, making them a potentially significant source of capacity. Many of the panelists highlighted that fact that developers that short-changed the early diligence phase of the project will have to deal with significantly higher costs later.

All panelists agreed that an ITC for energy storage would have a big impact on the energy storage market. It would allow full payback for a project in as little as 3-5 years, significantly improving the economics of the project development effort. It would also bring the tax equity investors into the energy storage market.

A key theme throughout many of the panelists' discussion was the educational level and perspective of capital providers. Many on the panel have spent significant time educating the capital providers they work with on the complexity of energy storage projects, and what aspects are similar, and which are different, from solar and wind project financing. One interesting aspect of lenders was that a number of the panelists described meeting lenders that "needed" a storage project in the portfolio, and thus willing to overpay for a potentially uneconomic or even poorly designed facility. A number of the panelists compared the relative experience between solar and storage projects. This has a direct impact on the comfort level of investors. Whereas solar has significant operating experience with more mature technologies, many of the project developers viewed storage as still having limited real-world experience, raising concerns as to how to model risk.

Risk management products and strategies were highlighted as managing regional and market specific risks. It was noted that insurance firms are beginning to take a closer look at the revenue stream of the facility and are beginning to segment different risk profiles based on the level of contracted revenue, and / or how much is based on a hedge. Insurance firms are also looking into the operations of the facility as well when evaluating projects. For this, they are emphasizing the need for standardized data availability in order to compare different projects, but also have transparency into the key sections of the facility's operation. This is all relevant in order to gauge not only design but also performance risk of the facility. These issues were felt to be important to the panel with respect to the OEMs warranty and how any limitations there could impact the use cases for the storage facility.

The second panel focused on the Capital Providers.

Capital providers are constantly evaluating what type of investment risks that are willing, and not willing to take. Key to this discussion was a discussion as to why the panelists thought about and why they were interested in the energy storage sector. An important challenge for all developers is to establish an internal learning capability to improve the project development process, reducing time, cost, and variability. For instance, solar project development is a proven process, with avenues to get funding through Notice to Proceed (NTP), with a number of private equity investors, including the important tax equity investors. Critical parts of the project development process included the EPC and O&M contracts (including liquidated damages) and warranty limitations. Within these contracts, it is important to determine who pays for what portion, and under what conditions. Defining where responsibility lies is critical for project developers that have limited experience with energy storage.

Without clearly defined areas of responsibility and performance criteria in the design documentation, later conversations with lenders can be problematic.

Long duration energy storage is gaining significant traction in the market, with increasing policy and regulatory efforts targeting the reliability benefits of the technology. Long duration energy storage is typically determined to be a project with 10+ hours of duration or more. There are a number of different technologies that can support this duration of storage, but all have different performance capabilities due to the various storage mediums. Some interesting technology/projects have been deployed, but some of these only have 1 deployment example. Unfortunately, without widespread understanding of the capabilities of these different performance characteristics, most investors simply look for “pumped hydro in a box.” A key challenge is how to make projects based on these technologies bankable. Issues here would be the longevity of the units, capital costs, operational costs, and risk management issues that affect insurance and debt costs.

Capital providers are increasingly confident around the use of lithium-ion systems but recognize the complexity surrounding their usage. Many speakers recognize that capability and quality complexity arise from the different cathode chemistries, and different OEM manufacturing processes. With the growing number and scale of deployed units, EPC contracts have shown to rise in importance. Increasingly, capital providers view fully wrapped EPC contracts as essential to minimize risk exposure, but also recognize that not all wraps are made equal.

Some of the panelists discussed their ongoing challenge of structuring the project deals to reduce operational risk and improve the bankability of the project. An important caveat brought out was that it is important to structure the projects on a sound technical and legal footing at the very beginning of the process. Warranties are important aspect of a project, with the understanding not just what is in the warranty, but what and who is backing the agreement.

The panelists provided some insights into their expected returns for different types of capital, and how that capital is provided. Many of the critical issues revolve around the merchant / contracted revenue split. Typically, developers would like to have 65% to 75% contracted revenue, although many developers are incorporating hedging strategies instead of fully contracted revenue. These hedging strategies typically last 3-5 years, allowing for the project to have some stable revenue in the early years to guarantee some of all of the debt repayment, with the final years of operation still generating power, but at a current assumption of fully merchant activity.

Equity financing was mentioned as a critical component of the project development process for both the capital, and structuring of the project for lenders, etc. Some discussion was mentioned about the current appetite for financing single units vs. fleet assets, with most agreeing that private equity still preferred to review projects one at a time instead of simply as a fleet of assets. Some interest continues to grow in developing a portfolio of project for financing, with a variety of projects considered a good basis to provide some value reliability due to the changing nature of the market. With the increasing interest in energy storage, there is a growing interest in storage from a different number of groups, from traditional renewable power investment firms, infrastructure groups, and increasingly from ESG investment groups wanting to have exposure to energy storage projects. A variety of business strategies are also expanding, spanning from stand-alone, hybrid project investments, to leasing energy storage assets for 5 years or so; these would be smaller, mobile units, but provide some insights into the growing creativity being put towards this market.

Corporate interest is also a growing area for customer development, and investment. ESG issues are expected to continue to remain critical, with energy storage playing a large role in how to leverage the value of other power assets. The list of corporations growing interested is also growing far

beyond what is typically expected, including more oil and gas firms looking to leverage the deep knowledge and understanding of how to address the importance of operations to market strategies.

A number of panelists also considered the issues surrounding debt providers. A critical issues all agreed to was that developers should get debt providers involved in the process early, instead of waiting for many of the specifics of the agreements to be baked in. It was mentioned that doing so will cost significantly more time and money to renegotiate the contracts, so it is important to get debt provider's opinions, as to what is bankable, and where possible problems lie. Debt providers with experience is really critical.

In closing, the conference chairman (Richard Baxter) highlighted a number of the key points raised at the Summit. Three areas in particular were of great interest: current market opportunities, bankability, and how the market is fundamentally changing.

- **Current market opportunities:** The current opportunities for energy storage assets are both what is available for them in a stand-alone role, but more importantly in how storage assets can leverage other electrical system equipment such as solar and wind generation equipment, and transmission systems. This was deemed critical because how one deploys the energy storage asset impacts the market strategy for the systems. For example, there have been innovative hybrid power systems introduced in the past that provided significant fuel and emission savings for a customer. The hybrid unit was deemed better in almost all technical qualifications verses the existing practice of using old systems from other parts of the network. Unfortunately, those old systems were fully depreciated, so the economic the economic cost of the innovative hybrid system was not cost-effective, as the current (bad) solution was a capital cost of zero, so the customer elected not to proceed.
- **Bankability:** Ensuring the bankability of non-lithium energy storage technologies will be crucial for the success of these new systems. This is important to a number of groups. First is non-lithium OEMs. Lithium ion is by far the technology of choice of developers, meaning that capital providers, insurance, system integrators and EPC firms will not have significant experience with the new technology, increasing the cost to construct and deploy systems made from these technologies. Secondly, emerging applications such as long duration energy storage (LDES). This is typically described as a technology issue, but LDES also presents a number of market challenges as well. Lithium-ion systems have been designed typically for shorter duration capabilities, only slowly (but steadily) moving towards 4-hour systems. Applications with shorter durations align themselves easier with existing market products and services. LDES systems will require actualizing many of the reliability centric values that these installations could provide but are hard to value as these applications do not have as well-developed market services market.
- **Changing market dynamics:** Capital providers and developers are getting more confident about how to use energy storage assets in successful market strategies. Additional experience will provide greater knowledge, and confidence for utilizing energy storage in a broad range of applications. However, as incidents like the TX ice storage illustrate, there are a number of impacts that developers may have not considered that can have extreme impacts. As it is becoming clear, energy storage assets are most valuable in a dynamic market environment. However, this also means that there is an increased need for risk mitigation. Therefore, understanding how energy storage system are important, not just for how to take advantage of the opportunities, but also reducing the downside risk.

APPENDIX D. ENERGY STORAGE FINANCING STUDY SERIES

The Energy Storage Financing study series is an outreach effort to the financial community funded by the U.S. Department of Energy's Office of Electricity through the Energy Storage Program at Sandia National Laboratories. This program is designed as a platform for a variety of U.S. DOE program efforts in order to accelerate energy storage technology investment and project development.

The Energy Storage Financing Study series is designed to investigate challenges surrounding the financing of energy storage projects in the U.S. and promote possible solutions, including:

- Promote Wider Access to Low-Cost Capital
- Improve Risk Management for Energy Storage Project Development
- Promote Greater Technology and Project Risk Transparency
- Reduce Project & Transaction Costs
- Supporting a level playing field for emerging energy storage technologies.

The components of the Study series have grown over time, and now comprises three components:

1. Summits: Current Market Insights
2. Workshops: Valuation Modeling
3. Reports: Document Lessons Learned

D.1. Energy Storage Financing Summits

The Energy Storage Financing Summit series is designed as a means to gain input from the financial industry on current market insights in the energy storage industry. These events are organized as Advisory Committee meetings as part of a series of studies funded by the U.S. DOE through Sandia National Laboratories. These events are free, but invitation only and not open to the press to encourage a frank and open discussion by leaders in the financial industry. The Summit series was designed with the following goals:

- Outreach to the Financial Industry.
- Allows DOE to engage directly with those shaping the storage industry.
- Promotes financial industry networking with storage industry leaders.
- Platform to promote DOE programs and resources.

There have been 10 successful DOE Energy Storage Financing Summit series events since late 2014. These events are held on the East and West Coast in order to reach as many of the energy storage industry participants as possible. The events have been held recently at Kirkland & Ellis, LLP, a leading global law firm specializing in project financing in the power sector.

Table 5-1. U.S. DOE Energy Storage Financing Summits

Year	Date	Location	Attendees
2021	Jan 26 & 27	Virtual	300 Attendees
2020	Sept 22 & 23	Virtual	150 Attendees
2020	Jan 14	NY, NY	170 Attendees
2019	Oct 22	SF, CA	74 Attendees
2019	Jan 23	NY, NY	146 Attendees
2018	Oct 6	SF, CA	104 Attendees
2018	Jan 18	NY, NY	124 Attendees
2017	June 7	Washington D.C.	84 Attendees
2017	Jan 11	NY, NY	68 Attendees
2014	Dec 16	NY, NY	65 Attendees

D.1.1. Prior Keynote Speakers

Table 5-2. Prior Keynote Speakers

Organizations	Keynote
California Clean Energy Fund (now New Energy Nexus)	Danny Kennedy
California Energy Commission	David Hochschild
California Energy Commission	Janea Scott
California Solar & Storage Association	Scott Murtishaw
Coalition for Green Capital	Reed Hunt
Energy Storage Association	Matt Roberts
Energy Storage Association	Troy Miller
New York State Energy Research & Development Authority	Alicia Barton
NY Green Bank	Alfred Griffin
Sandia National Laboratories	Babu Chalamala
Sandia National Laboratories	Ray Byrne
The World Bank	Chandrasekar Govindarajalu
U.S. DOE Loan Programs Office	Peter Davidson
U.S. DOE Office of Electricity	Imre Gyuk
U.S. DOE Office of Electricity	Eric Hsieh

D.1.2. Prior Summit Panelists

Table 5-3. Prior Panelists

Organization	Panelist
127 Energy	Ken McCauley
174 Global Power	Sean Yovan
8Minute	Luke Hansen
Able Grid Energy Solutions	David Cieminis
Advanced Microgrid Systems	Vishvesh Jharveri
AES Energy Storage	John Zahurancik
Alexa Capital	Gerard Reid
Anbaric Development Partners	Dan Dobbs
Ariel Re	George Schulz
Aypa	Moe Hajabed
Black & Veatch	Ralph Romero
C2 Energy Capital	Lee Feliciano
CALMAC	Mark MacCraken
Capital Dynamics	Benoit Allehaut
CIBC	Andrew Cleary
Cleantech Strategies	Russ Weed
CSA Group	John Rimac
DNVGL	Matt Koenig
Doosan Gridtech	Michael Atkinson
Dynamic Energy Networks	Steve Pullins
Electric Power Research Institute Inc.	Giovanni Damato
EnelX	Erik Richardson
Energi Insurance Services	Chris Lohmann
Energy Storage Consulting	Matt Koenig
Energy Storage Response Group	Nick Warner
esVolta	Kris Koomar

Organization	Panelist
Fluence	Dan Wishnick
GCube Insurance	Dan Cass
GE Power	Joe Heinzmann
GE Power	Mirko Molinari
GE Power	Troy Miller
Generate Capital	Ed Bossange
Half Moon Power	Michael Hastings
Hartford Steam Boiler (Munich Re)	John Roach
Hartford Steam Boiler (Munich Re)	John Stokes
Hitachi Capital	Chris Pagano
Hugh Wood Canada	Jen Aitchison
IFC	Peter Mockel
Investec	Ren Plastina
Javelin Capital	Patrick Norton
JLT Specialty	Sabbir Khandokar
Key Capture Energy	Jeff Bishop
KPMG	Nate Gabig
KRoad DG	Gerrit Nicholas
Lockheed Martin	Jaya Bajpai
Macquarie Group	Prashant Mupparapu
Macquarie Group	Caleb Waugh
Mitsubishi Electric Power Products, Inc. (MEPPI)	Charlie Vartanian
Momentum Energy Storage Developers	Davion Hill
Munich RE	Jay Goldin
Munich RE	Michael Schrempp
NEC Energy Solutions	Doug Alderton
NEC Financial	Herschel Salan
New Energy Risk	Tom Dickson
New Energy Risk	Jon Cozens

Organization	Panelist
Nexus Infrastructure Capital Management	Alan Dash
Nord/LB	Cherian Thomas
NY Green Bank	Jason Moore
NY Green Bank	Amy McCartin
Orix Infrastructure	Joshua Herlands
Orix Infrastructure	Barry Gold
Pacific Northwest National Laboratory	Jan Alam
Pacific Northwest National Laboratory	Di Wu
Pacific Northwest National Laboratory	Patrick Balducci
Pattern Energy	Terry Cantorna
Power Energy Risk (PERse)	Patrick Strubas
Powin Energy	Geoff Brown
Primergy Solar	Tim Larrison
Rabobank	Claus Hertel
Recurrent Energy	Adria Schulman-Eyink
Roth Capital	Craig Irwin
Rubicon Capital Advisors	Nick Sangermano
S&C Electric	Troy Miller
Sandia National Laboratories	Rodrigo Trevizan
Sandia National Laboratories	Ricky Concepcion
Sandia National Laboratories	Tu Nguyen
Sandia National Laboratories	Ray Byrne
Sandia National Laboratories	Babu Chalamala
Sentry Financial	Mark Nelson
Shell New Energies	Matt Tappin
Siemens Financial	John O'Brien
Siemens Financial Services	John O'Brien
SolarGrid Storage	Tom Leyden
Starwood Energy Group	Patrick Verdonck

Organization	Panelist
Starwood Energy Group	Ali Amirali
Stem	Polly Shaw
Strata Solar	Joshua Rogol
Strategic Management Group	Kelly Sarber
SunRun	Audrey Lee
SunRun	Joe Eisenberg
SUSI Partners	Asif Rafique
SUSI Partners	Gustavo Coito
Swinerton Renewable Energy	Craig Horne
Tortoise	Jerry Polacek
Tucson Electric Power Company	Ted Burhans
U.S. DOE Loan Programs Office	Dan Tobin
UniEnergy Technologies (UET)	Russ Weed
USI Insurance	Dixon Wright
Viridity Energy Solutions: an Ormat Company	Mark Stout
Vision Ridge Partners	Sam Cummings
Voltaiq	Tal Sholklapper
Wartsila Development Financial Services	Paul Smith
Wells Fargo	Jon Previtali
Willis Towers Watson	Danny Seagraves

D.2. Energy Storage Valuation Workshop

A workshop was added to the Energy Storage Financing Summit in 2019 to highlight U.S. DOE funded work at various laboratories and private industry on economic valuation modeling for energy storage project financing. Goals for these events include:

- Evaluate Valuation Models
- Compare Modeling Approaches
- Showcase Revenue Recognition / Value Stacking
- Highlight Results from Project Analysis

D.3. Reports

A final report is a key component of each Study and is designed to document the lessons learned from the research, interview, Summits, and Workshops.

- Improving the information, tools, and insights needed.
- Highlighting where the energy storage industry can adopt lessons learned from related markets that had similar challenges in their early years of development.

The list of reports in the study series are:

- Energy Storage Financing: A Roadmap for Accelerating Market Growth, SAND2016-8109
- Energy Storage Financing: Performance Impacts on Project Financing, SAND2018-10110
- Energy Storage Financing: Advancing Contracting in Energy Storage, SAND2019-14896
- Energy Storage Financing: Project & Portfolio Valuation, SAND2021-0830
- Energy Storage Financing: Operations & Strategy (Underway) SAND2021-xxxx

Energy Storage Financing: A Roadmap for Accelerating Market Growth

SAND2016-8109

The first study in the series, Energy Storage Financing: A Roadmap for Accelerating Market Growth [SAND2016-8109] laid the groundwork by evaluating the current market for financing energy storage projects and provided a roadmap for possible actions the U.S. Department of Energy could pursue. Project financing is emerging as the linchpin for the future health, direction, and momentum of the energy storage industry. Market leaders have so far relied on self-funding or captive lending arrangements to fund projects. New lenders are proceeding hesitantly as they lack a full understanding of the technology, business, and credit risks involved in this rapidly changing market. The U.S. Department of Energy is poised to play a critical role in expanding access to capital by reducing the barriers to entry for new lenders and providing trusted analytical benchmarks to better judge and price the risk in systematic ways.

Energy Storage Financing: Performance Impacts on Project Finance

SAND2018-10110

The second study in the series, Energy Storage Financing: Performance Impacts on Project Financing [SAND2018-10110] evaluated the impact of performance on financing projects and the methods to de-risk project development. Understanding performance is the key to risk management in energy storage project financing. Technical performance underlies both capital and operating costs, directly impacting the system's economic performance. Since project development is an exercise in risk management, financing costs are the clearest view into how lenders' perceive a project's riskiness. Addressing this perception is the challenge facing the energy storage industry today. Growth in the early solar market was hindered until OEMs and project developers used verifiable performance to allay lenders' apprehension about the long-term viability of those projects.

The energy storage industry is similarly laying the groundwork for sustained growth through better technical Standards and best practices. However, the storage industry remains far more complex than other markets, leading lenders to need better data, analytical tools, and performance metrics to invest not only to maximize returns, but also safely—through incorporating more precise performance metrics into the project’s documents.

Energy Storage Financing: Advancing Contracting in Energy Storage

SAND2019-2973

The third study in the series, Energy Storage Financing: Advancing Contracting in Energy Storage [SAND2019-2973] focused on the development of standardized project development contracts language to reduce the time and cost for project development and financing approval. The lack of standard financing contracts and supporting documents is inhibiting the growth of the energy storage industry. A number of firms are actively developing proprietary contract structures, resulting in a variety of unique attributes. This leaves the market disjointed for 3rd party financing groups looking to scale their lending. Lack of commonality and harmonization between developer and lenders raises project execution costs and causes delays in financing. Of special concern, projects based on emerging technologies are finding an increasing uphill climb for equal consideration by developers and lenders, leaving their potential commercialization in peril. This study will evaluate the development of standardized contracts to reduce the cost and contract approval time, learning from success in renewable energy project development. The goal of this study is to determine the key requirements for standard contracts in the emerging energy storage market and suggest avenues for possible industry led development.

Energy Storage Financing: Project and Portfolio Valuation

SAND2021-0830

The fourth study in the series [SAND2021-0830], Energy Storage Financing: Project and Portfolio Valuation is focused on evaluating the valuation of individual projects and portfolios to provide greater visibility for institutional investors wanting to support significantly larger deployment of energy storage assets. Energy storage project valuation methodology is similar to other power sector projects through evaluating various revenue and cost assumptions. Through the use of a standard proforma framework, the Study will evaluate the current tools available and highlight the risk issues pertinent to energy storage projects. Investing in portfolios of energy storage project are still an emerging challenge for institutional investors, and so the Study will also look at the specific challenges facing institutional investors with plans to invest large amounts of capital into the market.

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