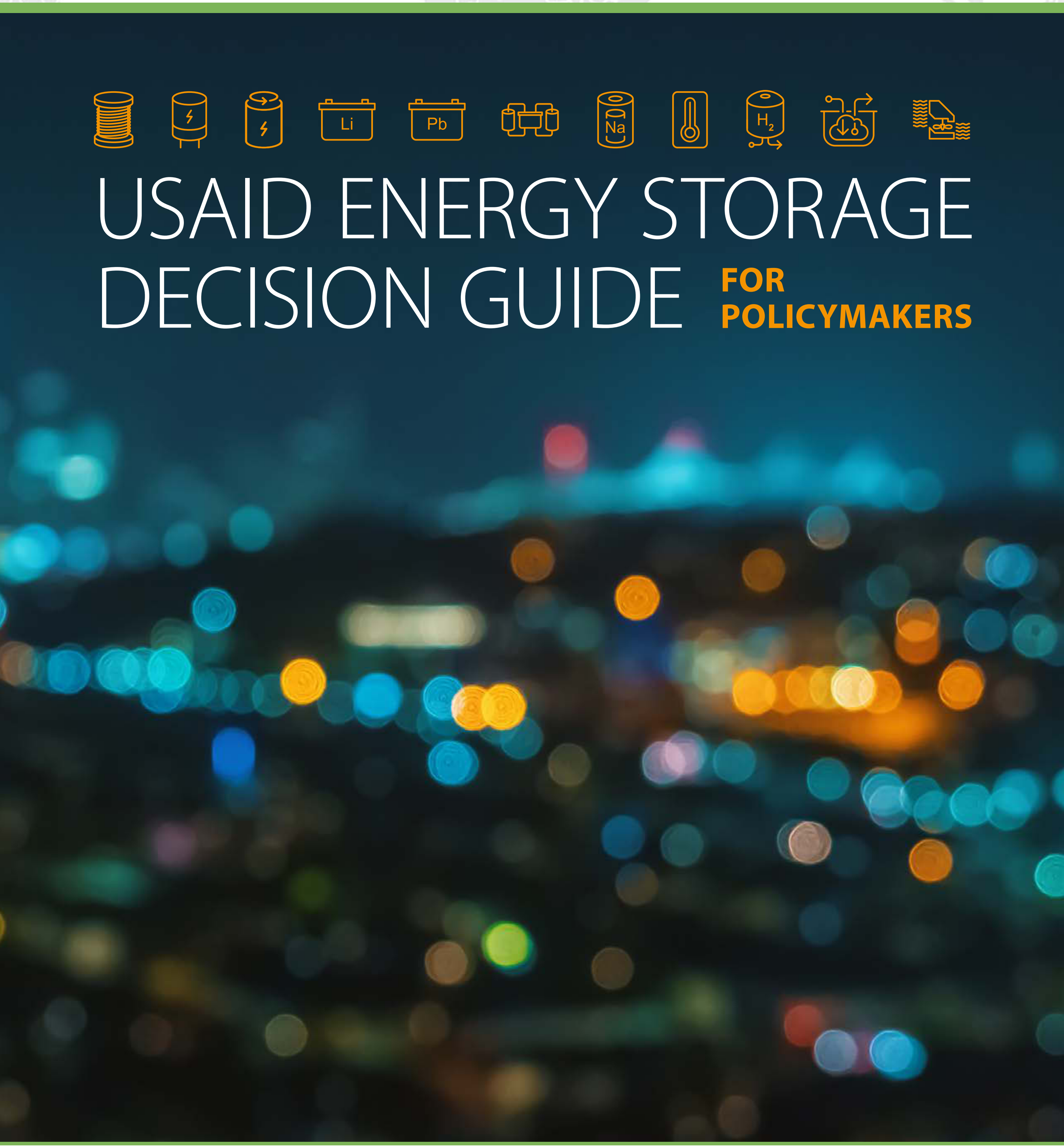
Greening the Grid



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Greening the Grid

USAID ENERGY STORAGE DECISION GUIDE FOR POLICYMAKERS

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List of Acronyms

BTM	behind-the-meter
CEM	capacity expansion model
DER	distributed energy resource
EBCE	East Bay Community Energy
ESMAP	Energy Sector Management Assistance Program
FERC	Federal Energy Regulatory Commission
GMP	Green Mountain Power
ISO	independent system operator
LCOE	levelized cost of energy
LCOS	levelized cost of storage
NREL	National Renewable Energy Laboratory
NWA	non-wires alternative
PCM	production cost model
PFM	power flow model
PG&E	Pacific Gas and Electric
PV	photovoltaic
ReEDS	Regional Energy Deployment System
USAID	U.S. Agency for International Development
VRE	variable renewable energy

Executive Summary

As countries worldwide aim to achieve their Nationally Determined Contributions (NDCs) under the United Nations Framework Convention on Climate Change Paris Agreement and update their NDCs in preparation for the 2021 United Nations Climate Change Conference, policymakers, regulators, and power sector planning agencies are increasingly faced with complex decisions about how to develop power systems that are reliable, affordable, and clean. Ambitious power sector transformation strategies, along with continually falling costs of renewable energy technologies, are driving higher levels of grid-connected variable renewable energy (VRE).[1] And because higher penetrations of VRE can drive an additional need for power system flexibility, decision makers are increasingly looking to emerging grid solutions such as energy storage to ensure reliable and cost-effective integration of VRE.[2]

Energy storage is one of several sources of power system flexibility that has gained the attention of power utilities, regulators, policymakers, and the media. Falling costs of storage technologies and improved performance and safety characteristics, particularly for lithium-ion battery energy storage, have made energy storage a compelling and increasingly cost-effective alternative to conventional flexibility options such as retrofitting thermal power plants or transmission network upgrades. In just the last decade, the cost of lithium-ion battery packs has dropped by 89% (BloombergNEF 2020). Cost declines for battery technologies have been driven by a combination of R&D efforts and increased manufacturing capacity for the electric vehicle sector, and this trend is projected to continue well into the next decade. Between 2018 and 2040, energy storage installations are projected to grow over 100 times (BloombergNEF 2019).

The purpose of this report is to arm relevant decision makers with the initial layer of information they need to understand energy storage and to make informed policy, regulatory, and investment decisions around grid-connected energy storage. While many of the case studies presented in this report are based on experiences from the U.S. and Europe, the lessons learned can be applied to power sectors in emerging economies. Importantly, this report covers topics related grid-connected energy storage for power sector applications. The term "grid-connected" implies that the storage system is interconnected to a centralized power system. Topics related to off-grid, micro-grid and mini-grid energy storage applications are not covered in this report, nor are procurement practices for energy storage.

Energy storage is poised to become a major component of power systems of the future.
Energy storage has been instrumental for the development of affordable and reliable electricity supply since nearly the inception of modern power systems. More recently, technology advancements and rapidly falling costs for newer technologies, particularly battery energy storage systems, have ignited interest among utilities, policymakers, and end-use electricity customers across the world about opportunities for grid-connected energy storage to provide cost-effective grid services and enable increased deployment of variable renewable energy (VRE) resources.

There are a range of established and emerging energy storage technologies.
While pumped hydropower is by far the most adopted technology for grid-connected energy storage, there are many types of energy storage technologies that are in various stages of research, development,

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[1] By power sector transformation, the authors refer to "a process of creating policy, market and regulatory environments, and establishing operational and planning practices that accelerate investment, innovation and the use of smart, efficient, resilient and environmentally sound technology options" (IEA 2019). For more information on such power sector transformations, see Cox et al. (2020).

[2] Power system flexibility is defined here as "the ability of a power system to reliably and cost-effectively manage the variability and uncertainty of demand and supply across all relevant timescales, from ensuring instantaneous stability of the power system to supporting long-term security of supply" (IEA and 21CPP 2018). For information on and sources of power system flexibility, see IEA and 21CPP (2018) and IEA and 21CPP (2019).

and commercialization as show in Figure ES-1. Lithium-ion batteries in particular have reached maturity and are experiencing significant deployment for shorter duration (i.e., 1 or 4 hours) applications. Other emerging technologies aiming to serve longer duration applications, such as flow batteries and power-to-gas, are in earlier phases of development and commercialization. In general, policy mandates, technological breakthroughs, and expanded manufacturing capacities point to a quickly evolving market for storage technologies.

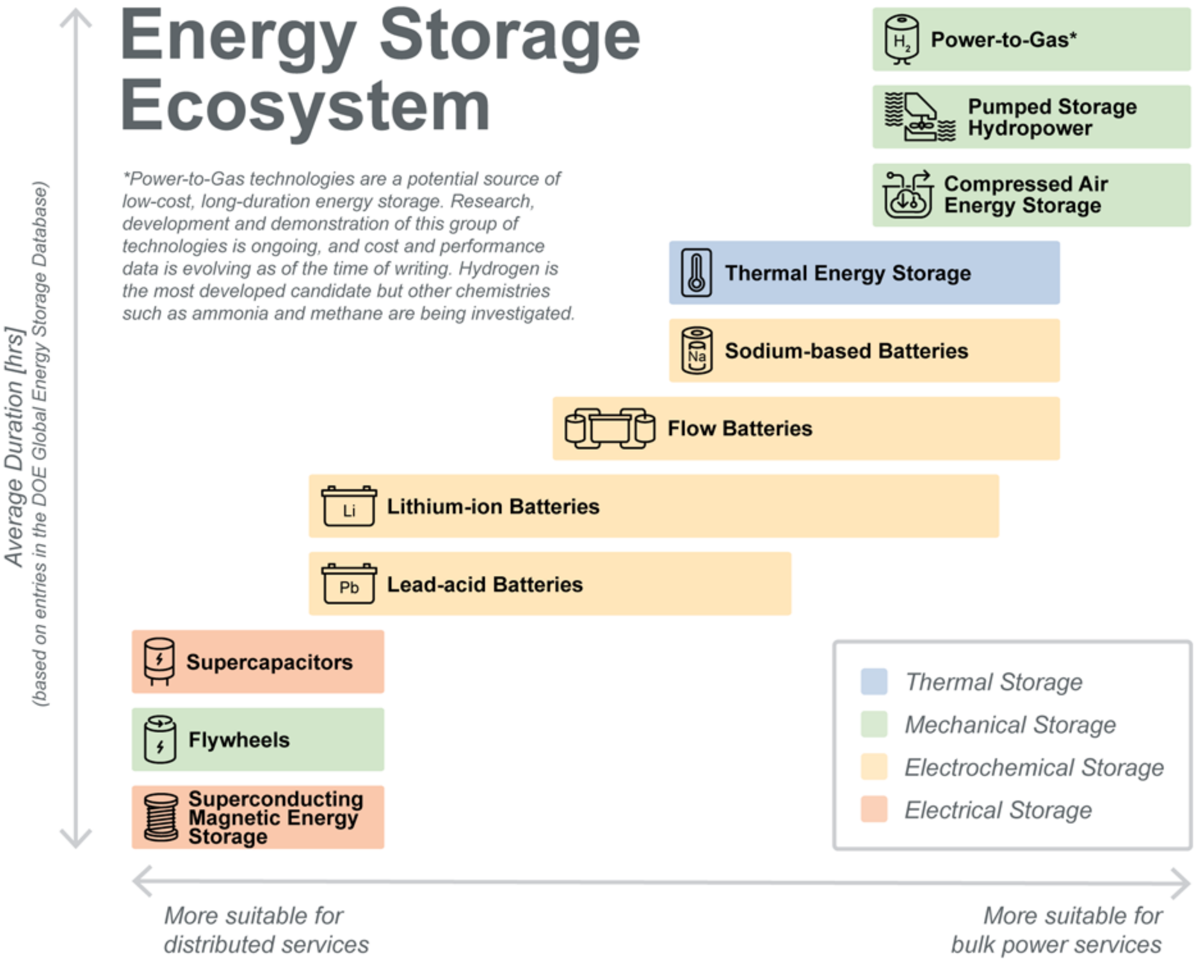

Figure ES-1. Ecosystem of energy storage technologies and services

Energy storage is part of a broader portfolio of grid solutions.
Energy storage is one group of technologies in a broader toolbox of options to support the flexibility, reliability, and resilience of power systems (Figure ES-2). While it is a promising technology, it may not be appropriate or cost-effective for all circumstances. Thus, when considering a decision to invest in energy storage, it is important to consider it in the context of the technical and economic merit of a wide array of options. Taking such a holistic view can lead to a least-cost and no-regrets portfolio of grid solutions.

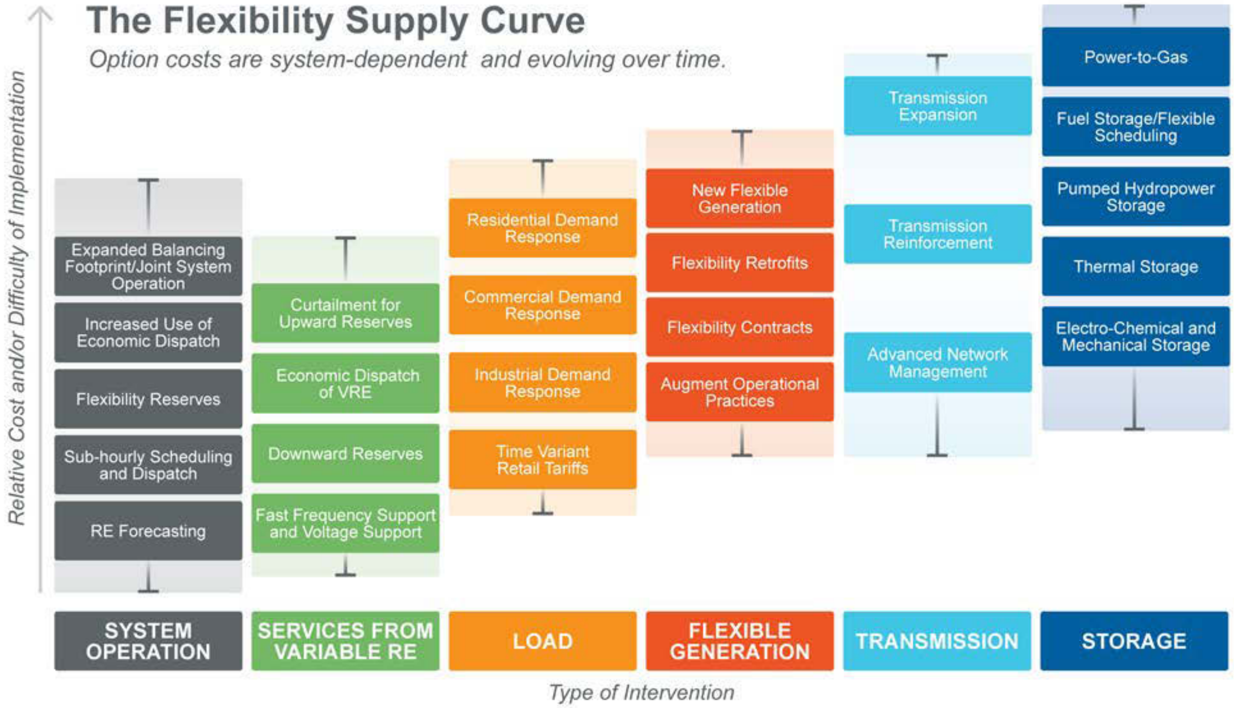

Figure ES-2. Example flexibility options. Relative costs and difficulty of implementation are illustrative, as actual characteristics are system-dependent.

Source: Modified from Cochran et al. (2014)

Energy storage can play a diversity of valuable roles in the power system.
Energy storage can provide a range of power system flexibility and reliability services for the power system over different timescales relevant to the system (Figure ES- 2). The same storage project can often provide multiple services to the grid. This multi-use approach to asset utilization is known as "value stacking." Value stacking can help improve overall energy storage utilization and is often discussed as a way to improve the economics of energy storage projects by ensuring storage can seek value across a range of services, rather than just a narrow subset of them. However, value stacking activities may require changes to policy and regulatory frameworks, as well as additional metering and communications infrastructure to be implemented in practice.

There are several key indicators that may suggest storage is appropriate to consider.
Decision makers can look at several indicative metrics to identify whether energy storage might be an appropriate solution to emerging system needs. These include increasing ramping requirements for conventional power plants, high or spiking energy production costs, high levels of renewable energy curtailment, regular local and/or regional power disruptions, and the presence of significant targets for renewable energy deployment or power sector decarbonization. While these metrics could be indicative of the need for storage, they may also be mitigated through other grid solutions. At the same time, energy storage can be included in long-term power sector planning to identify its potential role in the least-cost mix of future capacity and generation resources.

Analysis tools are critical for informing energy storage investment decisions.
Understanding the cost of prospective energy storage projects—especially relative to other grid solutions—is critical to inform investment decision-making. However, because of the multidimensional nature of electric sector technologies, "apples-to-apples" comparisons between storage and other solutions can be challenging. This challenge is compounded by the fact that a single storage project may provide

multiple value streams over various time horizons. Thus, it is critically important to utilize established power system analysis tools and methods, such as production cost models and capacity expansion models, among others, which compare the costs and benefits of a range of grid solutions to help inform decision-making. While models cannot eliminate all sources of uncertainty, they are an important source of insights and evidence to inform the decision-making process.

Energy storage can provide a distinct set of services depending on where it is connected to the grid. Energy storage technologies are technically capable of providing system services to segments of the power system at equal or higher levels of voltage. In practice, this means that transmission-interconnected storage cannot provide targeted flexibility services to the distribution system (e.g., distribution voltage support) or end users (e.g., customer resilience), and distribution-interconnected storage cannot provide services to end users but can do so for the transmission system. Behind-the-meter (BTM) storage, however, can offer services to all segments of the power system, but this may require installing appropriate metering and communication infrastructure, as well as changing utility operating practices and interactions between distribution and transmission system operators. This dynamic is depicted in Figure ES-3. Additionally, market and operating practices may need to change to: (1) permit storage devices to provide these services, and (2) create sufficient incentives to encourage storage devices to participate.

Figure ES-3. Energy storage can provide upstream grid services.

Transmission-connected storage can provide a range of services to the bulk power system, but comparing energy storage to other grid solutions is critical.

Transmission-connected storage can provide the bulk power system with peaking capacity, load shifting, transmission upgrade deferral, and a range of essential grid services. Evaluating the efficacy of storage investments for these services requires the use of established power system modeling tools, as well as substantiated assumptions about technology costs and performance characteristics. An analysis-based planning process can be used to evaluate the cost-effectiveness of energy storage as an alternative, or as a complement, to conventional bulk power system resources such as fossil-fueled power plants and high-voltage transmission equipment upgrades. Beyond robust planning, transmission-connected storage is enabled by, among others, clear technical interconnection processes and market participation rules, the ability for transmission-connected storage to seek remuneration for service provision, and regulatory support for storage pilots.

Distribution-connected storage can be an alternative to traditional distribution network investments and can also provide services upstream.

Distribution-interconnected energy storage is capable of providing many of the same types of services as more traditional distribution network investments, such as providing voltage support or helping meet increasing demand on local feeders. The types of services energy storage can provide to the power system and to customers, however, are also strongly influenced by its location in the power system. When deciding whether to invest in energy storage or more traditional solutions to grid issues, whether it is possible to provide upstream value should be incorporated into the decision-making process, as these upstream services can improve the overall economics of energy storage relative to other choices.

Decisions to invest in BTM storage are based primarily on decentralized consumer preferences rather than central planning.

Unlike systems interconnected at the transmission level or at the distribution level "in front of" the customer meter, BTM storage systems are typically owned and operated by consumers themselves to reduce bills or improve reliability of supply. As a result, consumers usually choose when and where to deploy BTM storage. Power consumers often have neither the incentives nor information to operate their systems in ways that directly benefit the broader power system. However, decision makers can enable interconnection of BTM storage and potentially guide customer decisions in a way that can also support grid needs through appropriate policy design. Decision makers can therefore focus their efforts on enabling deployment of BTM storage and creating incentives to align the interest of consumers with the broader power system.

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1 Introduction and Background

Energy storage has been an instrumental tool for the development of reliable electricity supply since nearly the inception of modern power systems. Power systems are tasked with maintaining the balance between supply and demand for electricity at all timescales, from sub-seconds to hours, to years, and all timescales in between. In general, storage technologies enable energy to be stored for later use when it is needed. Historically, energy storage in the power system has been mainly provided by conventional hydropower facilities that rely on large river dams to store water in flooded reservoirs. However, unlike conventional hydropower plants with natural water inflows, other energy storage technologies do not produce energy on their own and rely on other generators on the grid to produce electricity for charging. Different storage technologies can shift energy across different timescales to provide a range of flexibility, reliability, and resilience services for the power system.

Energy storage is also emerging as a key technology in power systems of the future. Technology advancements and increased manufacturing capacity have led to rapidly falling costs for newer technologies, particularly battery energy storage systems. These cost declines have ignited interest among utilities, policymakers, and end-use electricity customers about opportunities for grid-connected energy storage to provide cost-effective grid services, enable increased deployment of variable renewable energy (VRE) resources, and ultimately enable transitions to low-emission, flexible, reliable, resilient power systems.

1.1 Report Scope and Structure

This guide is intended for nontechnical power sector stakeholders who are tasked with making informed decisions about energy storage policies, regulations, rules, and standards. To make informed decisions about energy storage opportunities, decision makers need to understand:

1. Where energy storage fits in the broader context of grid solutions for flexible, reliable, and resilient power systems.
2. Where and when energy storage can play a role in their power system.
3. How to decide whether energy storage is a necessary, appropriate, and cost-effective investment in their power system.
4. How to identify the appropriate enabling policy "building blocks" that can be pursued to encourage energy storage projects once a decision has been made to do so.

This report focuses on grid-connected energy storage technologies. The term "grid-connected" implies that the storage system is interconnected to a centralized power system. Issues related to energy storage for mini-grids, as well as off-grid storage systems, are not discussed in this report.

Section 1 of this report provides a general overview of energy storage technologies and the services they can provide. Section 2 provides high-level guidance on how to decide if storage is the appropriate solution for emerging needs in the power system. Sections 3, 4, and 5 focus on the decision-making criteria, considerations, and policy building blocks for energy storage providing transmission-level, distribution-level, and behind-the-meter (BTM) services, respectively.

2 Review of Energy Storage Technologies

There are many types of grid-scale energy storage technologies that are in various stages of research, development, and commercialization as shown in Figure 1. Pumped storage hydropower is, by far, the most adopted technology for grid-connected energy storage (DOE 2020). In recent years, battery technologies using lithium-ion chemistries have become the dominant source of new grid-connected energy storage capacity (DOE 2020). See the U.S. Agency for International Development (USAID) Energy Storage Technology Primer for details about the capabilities, costs, use cases, and recent developments for different energy storage technologies.

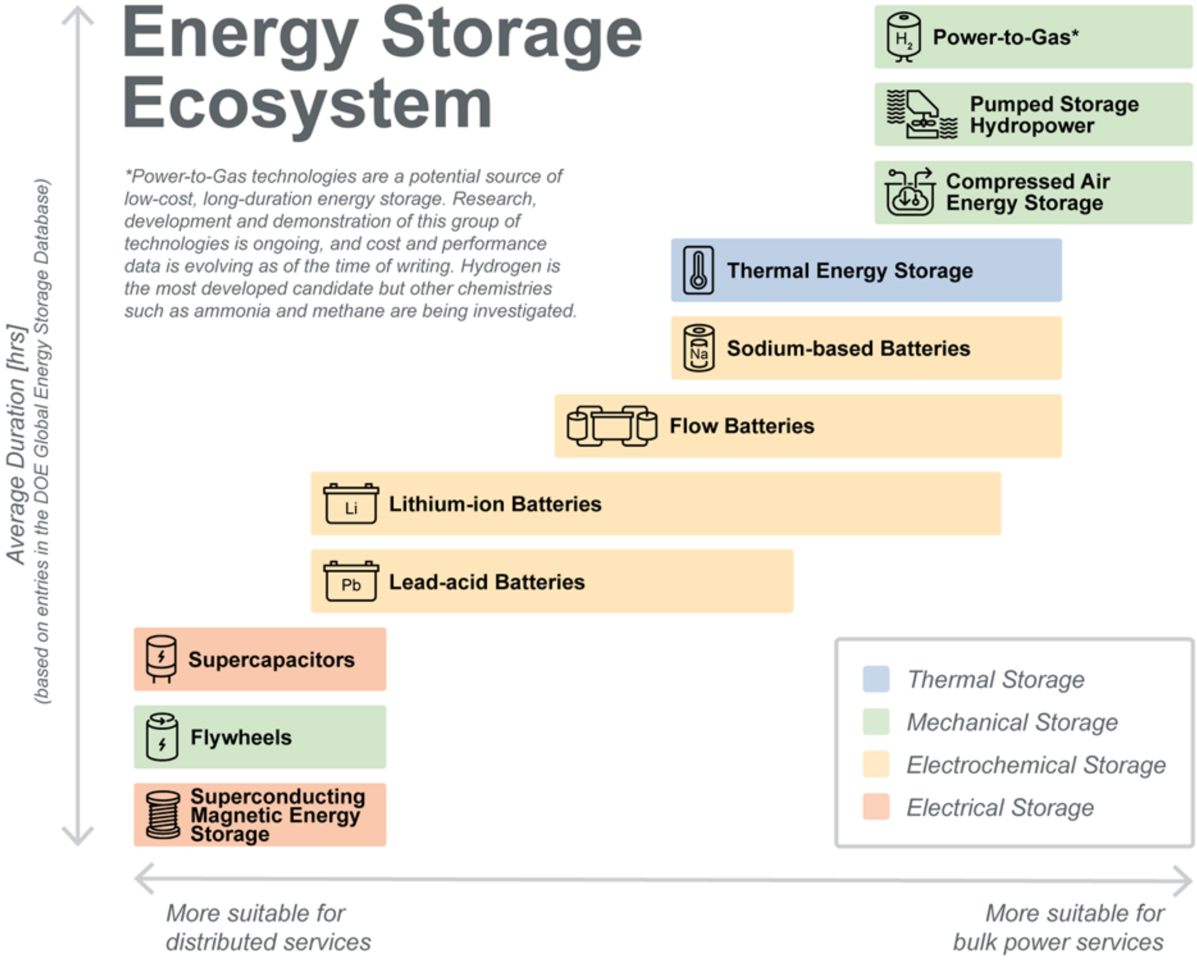

Figure 1. Ecosystem of energy storage technologies and services

Costs for some energy storage technologies, particularly for battery devices, have dropped significantly in the past decade. In addition to declining "hard" costs associated with technology improvements and the scale of manufacturing, another source of falling project costs is the "soft" costs associated with interconnection and permitting fees, labor, land acquisition, and other nonhardware costs. While hard costs may decrease with technology breakthroughs in research and increasing manufacturing capacity, soft costs can be addressed through policy and regulatory efforts to reduce the uncertainty and administrative burden around permitting and interconnecting the energy storage system. Reductions in both hard and soft costs can occur with increasing deployment as storage manufacturing capacity increases and supply chains mature, and as developers and regulators acquire more experience with the technology.

Policies and mandates are driving deployment of energy storage in some jurisdictions, for example, in the United States, China, Japan, India, and Europe. In the United States, energy storage has been bolstered by federal policies, such as Federal Energy Regulatory Commission (FERC) Order 841, which opened wholesale energy and ancillary markets to energy storage and FERC Order 755, which required that frequency regulation services be rewarded based on the quality of the service provided (FERC 2011; 2018). These two policies have helped enable energy storage to participate in wholesale electricity markets and ensured that the faster response times that many storage technologies are capable of providing are fairly reflected in compensation rates. Similar to Order 841, FERC Order 2222 has instructed system operators in the United States to develop participation models for distributed energy resources (DER) like distribution-interconnected and BTM energy storage to provide services to the wholesale market through aggregation, providing system owners with additional revenue streams. Complementary policies at the state level in the United States have further increased deployment within specific jurisdictions. For example, California's Assembly Bill 2514 requires larger load-serving entities to adopt energy storage procurement targets (Skinner 2010). States including Massachusetts, New Jersey, Oregon, and Virginia have also developed storage capacity installation targets (EIA 2020).

Asian markets are also adopting policies to encourage energy storage deployment. Several illustrative examples are provided in Table 1. China has energy storage development targets, as well as lithium-ion battery and pumped hydropower deployment manufacturing regulations in the Guiding Options on Energy Storage Development Action Plan (China Energy Storage Alliance 2017). In Japan, the Stationary Battery Road Map was developed in 2013 to guide Japan's battery storage deployment between 2013–2030 (Tomita 2014). In India, the central government is supporting the establishment of a local lithium-ion manufacturing supply chain, as part of its broader Make in India program and through the recently formed National Mission on Transformative Mobility and Battery Storage. India is considering several storage-friendly policies such as research and development investments, establishing manufacturing consortiums, streamlining permitting, and offering tax incentives (NITI Aayog and Rocky Mountain Institute 2017).

Table 1. Examples of Policies and Regulations That Support Energy Storage Deployment

Country or Jurisdiction	Policies and Regulations	Summary
United States	FERC Order 841 FERC Order 755 FERC Order 2222	Open electricity markets to energy storage participation and help ensure fair compensation for energy storage devices.
Massachusetts, New Jersey, Oregon, Virginia	Storage capacity installation target	Targets indicate government support for energy storage through grant programs, preferential tax treatment and/or mandates for electric utilities to procure energy storage (details vary by jurisdiction).
Japan	Stationary Battery Road Map	A collection of subsidy programs for specific energy storage technologies, as well as simplified application and permitting processes for energy storage projects.
India	National Mission on Transformative Mobility and Battery Storage	Supports the establishment of a local lithium-ion manufacturing supply chain through a 5-year phased program to set up large-scale cell manufacturing plants.

3 Energy Storage Is Part of a Broader Portfolio of Grid Solutions

It is important to recognize that energy storage is one tool in a broader toolbox of options to support the flexibility, reliability, and resilience of power systems. Some of these options are technical solutions and involve new investment in hardware (e.g., a new flexible power plant) or software (e.g., more accurate renewable energy forecasting), whereas others are institutional in nature (e.g., increased coordination with neighboring power systems). There is a large body of existing practice and literature related to these options. **When considering a decision to invest in energy storage, it is important to consider the technical and economic merit of a wide array of options that can lead to a least-cost and no-regrets portfolio of grid solutions.**

Table 2 highlights key resources on several categories of grid solution options that decision makers can explore for additional information. Figure 2 shows additional grid solutions, organized approximately by price and category of the intervention. Decision makers interested in improving power system flexibility and reliability can begin investing in low-cost options for their power system (those to the left of Figure 2), employing more expensive interventions as the need for flexibility grows.

Table 2. Additional Educational Resources for Grid Solutions

Category of Grid Solution	Example Options	Key Resources
System Operation	Increased use of economic dispatch; faster grid dispatch; renewable energy forecasting	Tian and Chernyakhovskiy (2016) Denholm and Cochran (2015)
Markets	Improved energy market design; joint market operation	Ela et al. (2014) IRENA (2017; 2019c) Baritaud and Volk (2014)
Services from VRE	Provision of downward reserves voltage and frequency support, and other services	IEA-RTD (2016)
Load	Industrial demand response; aggregated commercial and residential demand response; sector coupling	Denholm (2015) IEA-Task 25 (2020a)
Flexible Generation	Changes to plant operational practices; flexibility retrofit investments; new flexible generation	IEA and 21CPP (2018) IRENA (2019b)
Transmission	Transmission upgrades; Flexible AC Transmission Systems; Dynamic Line Rating; Renewable energy zones	EEI (2019) EIA and ICF (2018) IEA (2019) PGCIL (2017) IEA-Task 25 (2020c) IRENA (2019e; 2019a)
Storage	Reservoir hydropower storage; electrochemical storage	Few, Schmidt, and Gambhir (2016) Bowen, Chernyakhovskiy, and Denholm (2019) IEA-Task 25 (2020b) IRENA (2019g; 2019f; 2019d)

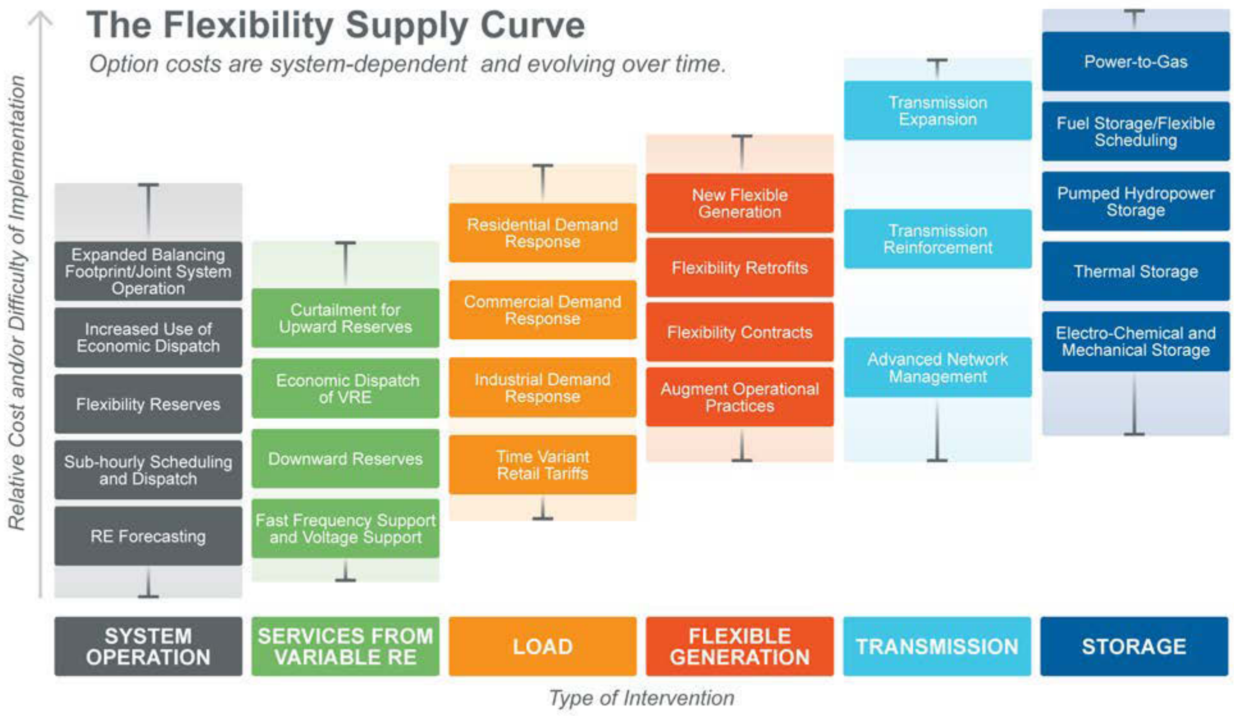

Figure 2. Grid flexibility options and their relative cost and/or difficulty of implementation

Note: Relative costs and difficulty of implementation are illustrative, as actual characteristics are system dependent. Figure modified from Cochran et al. (2014).

3.1 Key Analyses for Energy Storage Decision-Making

The costs and benefits of grid solutions can be compared using existing tools and study methodologies in both near- and long-term planning exercises under the framework of a grid integration study.[3] Grid integration studies are conducted using a combination of different types of tools. Although grid integration studies can be powerful tools for comparing alternative grid solutions, accurately modeling energy storage systems is a complex endeavor, and decision makers should consider the limitations of properly modeling storage when using these analyses to compare storage to other options (see Text Box 1).

Capacity expansion models (CEMs) create technically sound, least-cost investment plans for the power system to meet demand and reliability constraints over time. In the context of comparing grid solutions, they are most often used to create scenarios of cost-optimal portfolios of the future mix of generation, storage, and transmission capacity expansion. In general, it is a best practice to create multiple future portfolios, or scenarios, that reflect uncertainties in key assumptions such as technology costs, electricity demand growth. These portfolios are then used as a baseline in more detailed production cost models (PCMs) to explore the operational value of various grid solutions. Analysts can use CEMs to understand if certain grid solutions are economically optimal for the system in the context of other planned investments and expected demand growth. For example, the National Renewable Energy Laboratory's (NREL's) Regional Energy Deployment System (ReEDS), an open-access CEM tool, is used to produce

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[3] For more detailed information on grid integration analyses and how to design and implement them, reference Katz and Chernyakhovskiy 2020.

"Standard Scenarios" for the development of the U.S. power grid until 2050 (Cole et al. 2020). However, because CEMs examine questions of optimal investment over multiple years or decades, they are limited in their ability to characterize the short-term flexibility and reliability attributes of grid solutions, which may limit their value when used in isolation.

PCMs simulate the technical and economic *operation* of the power system—typically for a period of 1 year—and can characterize the flexibility and reliability attributes of various grid solutions with relative accuracy, from timescales of minutes to months. PCMs can be used to ask "What if" questions about prospective decisions to deploy grid solutions, as well as the value of multiple grid solutions working together in concert, quantifying the operational costs of the power system over a given modeled year (IEA and 21CPP 2018). These models can be used in tandem with CEMs to estimate the economic and operational impact of a set of grid solutions under future power system conditions. They are a powerful tool to compare and contrast the operational value of various grid solutions, including storage.

Power flow models (PFMs) and related tools are used to simulate the physical movement of electricity through the power system during both normal steady-state operations and during periods of system stress. In the context of comparing grid solutions through grid integration analyses, PFMs can be used to validate the value of various grid solutions by assessing their ability to support the stability and reliability of the power system under various operating conditions. PFMs can also be used to evaluate the ability of grid solutions, including energy storage, to defer upgrades to transmission grid equipment, reduce wear-and-tear of existing network equipment, and/or delay investments in new grid infrastructure. PFMs are an important tool for validating the technical feasibility of portfolios of grid solutions arrived at through CEM and PCM analyses. In some cases, additional analyses including short-circuit analysis and dynamic stability analysis are used to further verify and validate CEM and PCM results. Given the high granularity of PFMs and related tools, they are typically only used to analyze a snapshot (of up to several minutes) of power system operations.

Avoided network infrastructure valuation assessments. Certain grid solutions, including storage, can be deployed to cost-effectively defer or even eliminate the need for traditional network infrastructure investments in locations where existing network capacity is not sufficient to meet expected electricity demand. To inform investment decisions for these "non-wires alternative" (NWA) solutions, cost-benefit analysis exercises can be undertaken to examine the net avoided cost of individual or portfolios of grid solutions such as energy storage. This approach can be used to create a cost savings metric associated with each NWA that can help inform investment decisions.[4]

Project-level techno-economic assessments of grid solutions. Techno-economic performance assessment tools are used to design individual grid solutions and characterize their expected technical operation and financial performance. While such tools are most frequently employed by project developers, policymakers, and regulators can also use these tools to evaluate projects and benchmark contract prices for proposals received from utilities and/or the private sector. Policymakers and regulators can also employ such tools when they are designing new forms of DER compensation to understand the customer economics implications of new schemes. NREL's System Advisor Model is a free techno-economic software model that can help to inform developers, regulators, and policymakers on both project-level design/investment decisions and broader public policy decisions.

End-use adoption modeling. Customers adopt various DERs, including BTM storage, based on individual customer preferences, which can be difficult for decision makers to discern. It is important,

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[4] For more information on methodologies to assess avoided network infrastructure investment value of grid solutions, see: *Locational Value of Distributed Energy Resources* (2021).

however, for power system planners to be able to adequately predict where and when adoption of various DERs will occur, as these can influence the planning process. Adoption models, such as NREL's dGen tool, can provide an estimate of the levels of DER investment that are likely to occur in a given region and time. Such models can also relate important information on how certain factors like cost reductions, compensation mechanisms and other policy interventions are likely to impact when and where BTM storage will be adopted.

Text Box 1. Getting Energy Storage Right in Power System Modeling

Energy storage is a flexible asset for the power system, able to act as both traditional generation and a transmission and distribution asset (Text Box 3). Depending on the technology, energy storage can typically respond more quickly and accurately to signals than traditional assets. However, compared to more traditional assets, energy storage's ability to charge or discharge depends on how much it is charged (i.e., the state of charge), making its operation energy-limited.[5] These characteristics can complicate efforts to simulate energy storage's behavior and its effects on the power system. Without being able to reliably model energy storage in their grids, distribution and transmission system operators may be hesitant to adopt storage. They also may be less equipped to convince regulatory commissions of the merits of adopting storage in planning proposals. This lack of modeling capabilities can be particularly impactful for energy storage providing multiple services to power system market segments, as inadequately modeling the value of all of these services makes it challenging to make fair comparisons with more traditional investments (Bhatnagar et al. 2013). Decision makers can help address this issue by encouraging the use of sufficiently detailed modeling tools and explicitly requiring power system operators to consider storage in their planning exercises.

3.2 Services Provided by Energy Storage

Energy storage can provide a range of power system flexibility and reliability services for the power system. Figure 3 shows the categories of system services that can be provided by grid-connected energy storage systems. For more detailed information on system services and specifically the services energy storage is capable of providing, see (Fitzgerald et al. 2015) and the section "What services can batteries provide?" of (Bowen, Chernyakhovskiy, and Denholm 2019). Importantly, these potential services are provided over different timescales. Some power system issues require near-immediate service provision to be addressed, whereas others might be resolved over the course of hours, days, or even seasons.

The duration of an energy storage device often determines which services it can provide. For example, some energy storage technologies like flywheels and supercapacitors have short durations on the scale of seconds to minutes, making them better suited for applications that require quick reaction times for limited timespans (e.g., fast frequency response service). Other technologies, such as compressed air energy storage or pumped storage hydropower may react more slowly but can maintain output over the course of hours or even days, making them better suited for longer-duration applications (e.g., providing peak capacity). Declining costs of energy storage technologies, particularly lithium-ion battery storage, opens the potential for larger capacity *and* longer-duration energy storage projects to provide a broader range of grid services, including medium-term energy and capacity services (Schmidt et al. 2019).

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[5] State of charge, typically expressed as a ratio or percentage, is the amount of a storage device's energy capacity that is being used at any given time. For example, a fully-charged battery will have a state of charge of 100%, and a half-charged battery will have a state of charge of 50%.

Text Box 2. The Importance of Storage Duration

One key dimension of energy storage projects is the *duration* of time for which a particular project can store energy. Lithium-ion battery technologies, for example, tend to be deployed for shorter duration applications (e.g., 1 to 4 hours) due to the high cost of building larger storage capacities. Shorter duration applications are increasingly economic for providing quick-response grid services, balancing supply and demand over the course of a day, and providing peaking capacity. Medium duration storage (e.g., 4 hours to 12 hours) may also begin to see market opportunities for capacity adequacy and daily energy shifting services as it grows more cost- effective (Denholm and Margolis 2018). However, as growing quantities of VRE are deployed in many power systems, there is an increasing interest in longer duration storage (sometimes referred to as "seasonal storage") to shift energy from multi-month periods of surplus VRE to periods where VRE production is at a deficit—for these applications, traditional storage technologies may not be economically viable. However, along with the highly established yet geographically constrained pumped storage hydropower (PSH) approach, there are many emerging long-duration energy storage technologies being actively researched and deployed by industry, though no technology has emerged as a clear winner as of the time of this writing.

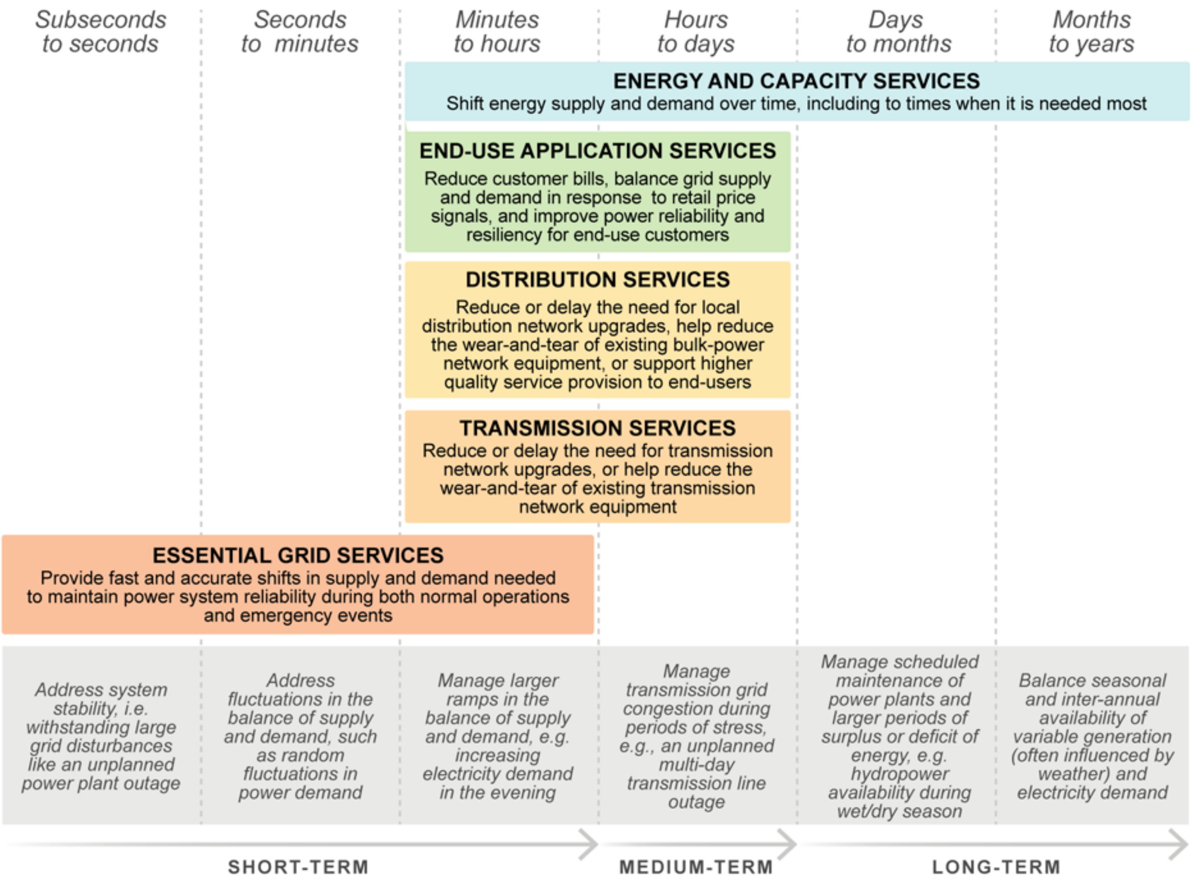

Figure 3. Timescales of grid services from energy storage

3.3 Energy Storage Value Stacking

As illustrated in Figure 3, many of the services critical to the reliable operation of the power system are needed on different timescales. As the services are needed with different frequencies (e.g., either every few minutes or only a few days out of the year) and for different durations (e.g., either for a few seconds or sustained for several days), the same project can provide multiple services to the grid (see Figure 4). This multi-use approach to asset utilization is known as "value stacking." Value stacking can help improve overall energy storage utilization and therefore the economics of energy storage projects by ensuring that it can seek value for providing a range of services, rather than just a narrow subset. Although the same storage system is able to provide a wide range of services, some services may be mutually exclusive based on design decisions for the storage system. For instance, a storage system designed to provide high frequency, short duration services may not be capable of or optimally designed for infrequent, longer duration services. The higher utilization rates enabled through value stacking may also lead to faster degradation in energy storage systems, as they are dispatched more often than if they only provided a narrow set of services. As energy storage has a limited charge at any given time, an asset must carefully prioritize the services it can provide at any given time to ensure it has availability for high priority services (Bowen, Chernyakhovskiy, and Denholm 2019).

Here, there is a role for policymakers in providing rules or guidance to storage owners to ensure that critical reliability services are prioritized over other value-seeking activities.[6] In general, the benefits of value stacking must be carefully considered against technical consideration and constraints when evaluating and designing the appropriate storage system. Finally, in addition to these technical considerations, there may be regulatory or market barriers that prevent energy storage systems from maximizing their value to the system. Some jurisdictions have sought to specifically address these barriers while ensuring the reliable provision of services from storage (CPUC 2018).

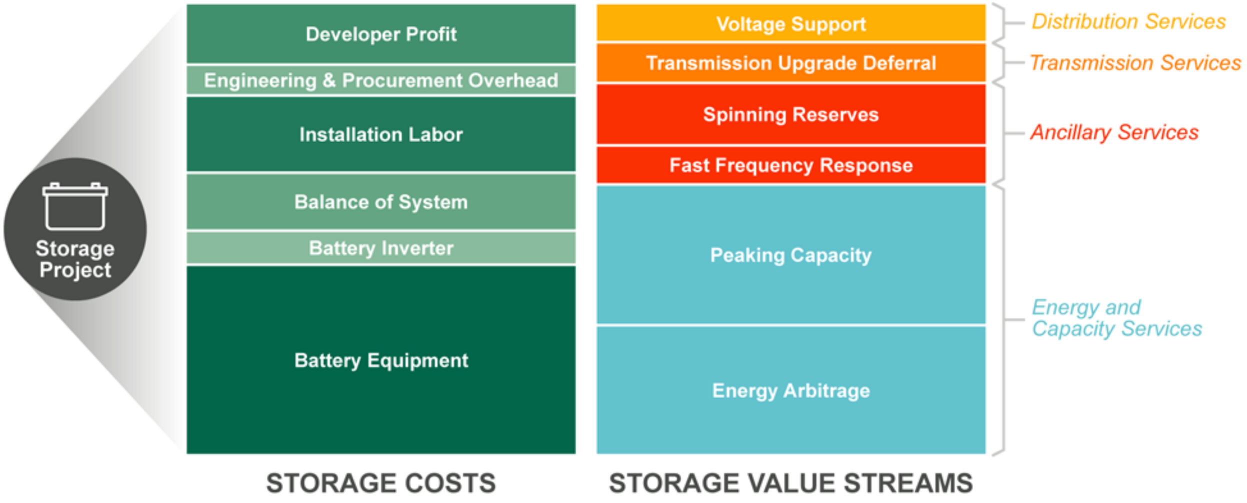

Figure 4. Example of value stacking for a hypothetical energy storage project compared to project costs

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[6] For instance, California has promulgated rules that ensure that services that bolster system reliability (e.g., operating reserves) are prioritized over other non-reliability services (e.g., energy arbitrage) (CPUC 2018).

Text Box 3. Is Energy Storage a Generation or Network Asset?

Energy storage is capable of providing a wide array of services, not only at different "levels" of the power system (transmission, distribution, and BTM), but also functioning as a different type of traditional asset. For some services, energy storage resembles traditional generation, providing energy and essential grid services to the bulk power system, or meeting on-site demand with stored energy from a paired rooftop solar installation. For other services, energy storage acts more like a traditional transmission or distribution network asset, reducing congestion or providing voltage support to defer grid upgrades. Importantly, the same energy storage asset can likely provide services in both categories and may be required to sell services in both categories in order to achieve economic viability. This can cause issues in some power systems due to rules about how traditional ratepayer-funded generation and transmission/distribution assets are allowed to be compensated for their services.

While existing rules are usually sufficient for assets that provide services in either of the two categories, complications can arise for energy storage-providing services in both the generation and network market segments. For instance, a utility may wish to purchase an energy storage system to defer the need for additional distribution or transmission investment. However, if the storage system only provides "distribution investment deferral" as a service, it may be quite expensive relative to conventional network investments, and, depending on the shape of the load curve, it may only be needed a few hours per year, leaving the storage system underutilized. Providing additional services in a wholesale market, however, may raise concerns about: (1) the availability of the storage device during peak distribution network demand; (2) how effectively the utility is operating the storage device to seek value in the wholesale market; (3) how to allocate the value created by the storage device in the wholesale market between ratepayers and the utility; and (4) how to design an *ex-ante* rate increase for a ratepayer-funded storage asset without advance knowledge of how much value it might create in the wholesale market.

One potential route to circumvent these issues under existing regulatory paradigms is to bypass utility ownership of the storage asset altogether. In the case of the previous example, the utility could competitively procure access to a privately owned storage device during distribution network congestion events (adding the cost of the contract to the utility's regulated operational expenditures). Outside of prespecified times, however, the storage developer would be free to seek revenues in the wholesale market. This would enable the competitively procured contract price from the utility to better reflect the net value of the storage asset while ensuring that ratepayers do not take on undue risk in financing the project.

Another possibility would be to create locally appropriate, customized regulatory approaches that classify what share of the energy storage's utilization supports traditional cost-of-service network services (and therefore can rightfully be recovered from customers through retail tariffs), and what share of the foreseen utilization will be engaged in market-based value seeking. Regulatory approaches would also have to determine a suitable allocation of financial benefits of wholesale market participation between ratepayers and the utilities, both honoring the fact that ratepayers financed the project while incentivizing the utility to operate the storage asset effectively.

While both approaches are novel and may require careful regulatory consideration, allowing energy storage to provide services across cost-of-service-based and market-based compensation categories may be critical to ensuring the economic viability of storage in markets.

4 Is Energy Storage the Right Solution for My Needs?

Energy storage is one of several options for supporting grid flexibility, reliability, and resilience. While the power system context in each country, region, and utility territory is unique, decision makers can look at several indicative metrics to identify whether energy storage would be an appropriate solution to emerging system needs. Table 3 lists five characteristics of a power system that may indicate a need for power system flexibility solutions, including energy storage. In some cases, proactive approaches to increase power system flexibility, particularly cost-effective operational changes, can help to delay or avoid costly infrastructure investments such as energy storage. See Table 2 and Figure 2 for examples of preemptive interventions other than energy storage.

Table 3. Key System Characteristics Indicating a Potential Role for Energy Storage*

Power System Characteristics	Potential Role for Energy Storage
Rapid growth in peak electricity demand and ramping requirements	While the shape and duration of peak demand periods will influence its efficacy, energy storage can be evaluated as an alternative to conventional flexibility and peaking power resources such as gas-fired combustion turbines.
Spiking power prices	Periods of high energy production prices can indicate insufficient power system flexibility to meet demand. Energy storage can be utilized to meet demand during high-priced periods with previously stored energy, a function often referred to as "arbitrage."
Renewable energy curtailment	High levels of VRE curtailment can be caused by an insufficient ability to back down conventional generators or deliver energy during periods of high VRE availability. Energy storage can be charged with this excess energy to meet demand at a later time, reducing curtailment.
Local and/or regional power disruptions	Disruptions to electricity supply can be indicative of technical and/or operational issues that can potentially be alleviated with energy storage. Energy storage devices can be used to maintain reliable power supply during routine system disturbances (i.e., transmission voltage issues and/or generator outages) as well as during extreme weather conditions.
High targets for solar PV deployment	Power sector transformation toward low-carbon and high renewable energy power systems, particularly with high shares of solar PV generation, can necessitate a transition to highly flexible and nimble system operations. Energy storage is one tool in the toolbox for system operators as they manage increasing variable and uncertain electricity supply from solar.

* See (Rose, Koebrich, et al. 2020) for a detailed discussion and comprehensive list of system characteristics, polices, and regulations that can help enable energy storage deployment.

Text Box 4. Policy and Regulatory Readiness Environment for Utility-Scale Storage in India

In 2020, the National Renewable Energy Laboratory undertook an assessment to identify potential barriers for utility-scale energy storage in India. The assessment used a methodology developed by Rose, Koebrich, et al. 2020 to apply a series of 20 criteria that may impact opportunities for utility-scale energy storage deployment in the country. The criteria are divided into three categories: system characteristics, policies, and regulations. Figure 5 shows the evaluation scheme used to rate each of the 20 criteria evaluated in the readiness assessment.

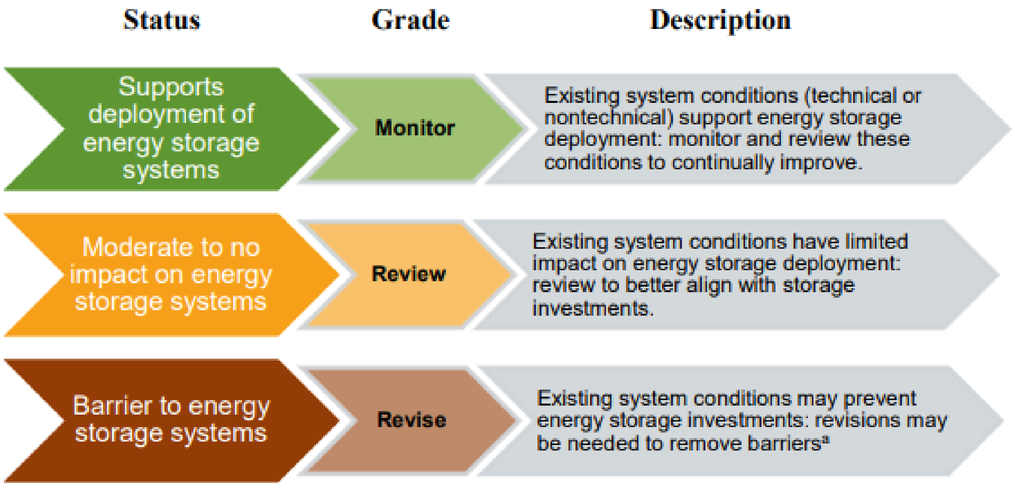

Figure 5. Evaluation scheme for energy storage readiness assessment

Note: Figure from Rose, Koebrich, et al. 2020 used with the authors' permission

The results of the readiness assessment show that several aspects of the policy and regulatory environment in India currently present barriers for energy storage deployment. For example, storage is included in national planning but absent from national energy policies and programs. On the regulatory side, energy storage is not eligible to provide most essential grid services such as fast-response operating reserves. In general, the assessment finds that policy and regulatory barriers are "mostly due to an absence of storage considerations in current frameworks rather than poorly designed energy storage policies or rules" (Rose, Wayner, et al. 2020). See Rose, Wayner, et al. 2020 for details about each of the 20 criteria and status grades for India.

Other countries and jurisdictions can use the methodology developed in Rose, Koebrich, et al. 2020 to evaluate if there are specific barriers for energy storage that can be addressed with relatively low-hanging-fruit policy and regulatory interventions.

4.1 Where Can Storage Be Deployed?

In practice, energy storage technologies generally do not provide targeted grid services to segments of the power system with lower voltage levels than the voltage level they are interconnected to. However, they can provide targeted services, like voltage support and grid frequency regulation, to higher voltage levels. For example, an energy storage device connected to the high voltage transmission network cannot directly provide voltage support services to the low or medium voltage distribution network, whereas storage connected to the distribution network can provide various services to either the distribution or transmission network (Figure 6). Although technically capable of providing services to higher voltage segments of the power system, distribution-interconnected storage (both front-of-the-meter and BTM) may need additional metering and communication infrastructure to technically provide such services. Additionally, market and operating practices may need to change to: (1) permit such assets to provide these services; and (2) create sufficient incentives to encourage these assets to participate. For more information on how to engage distribution-interconnected storage, see Text Box 11.

Figure 6. Energy storage can provide targeted upstream grid services.

The subsequent sections will provide the reader with the requisite background information and descriptions of the necessary analytical approaches to understand if storage is the appropriate solution for solving their particular set of issues. It will also provide an abbreviated description of the "building blocks" of the enabling framework and set of conditions that should be in place to plan, procure, interconnect, and fully yield the value of a storage project.

4.2 Understanding the Cost of Energy Storage

Understanding the cost of prospective energy storage projects—especially relative to other grid solutions—is critical to informing investment decision-making. Decision makers typically seek to identify the most cost-effective, profitable, and/or most efficient energy storage technology for a range of grid applications. They also typically need to assess the competitiveness of energy storage against conventional technology solutions. However, because of the multidimensional nature of electric sector technologies, "apples-to-apples" comparisons between storage and other solutions can be challenging. This is chiefly because electricity technologies can provide multiple grid services, in some cases simultaneously, requiring detailed modeling tools and assumptions to make cost-benefit comparisons between technologies possible.[7] Storage projects have an additional layer of complexity because they have both power capacity (in MW) and storage capacity (in MWh) as key dimensions. Furthermore, as storage projects can provide multiple services, a simple cost comparison for a single type of service provision (e.g., the cost of peaking service provision for a battery) may not capture the entire economics of a project. This means that simple cost metrics cannot be used to easily and directly compare energy storage with, for example, the cost of generation projects like a natural gas or coal plant.

In practice, there are several metrics that are commonly used to describe the cost of an energy storage project. Figure 4 describes these key cost metrics that are used in the industry. Because energy storage does not produce energy, traditional metrics like levelized cost of energy (LCOE) must be adapted to represent the unique qualities of energy storage devices. Storage-specific cost metrics like levelized cost

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[7] See Mai et al. (2021) for a detailed discussion of cost metrics and methods to evaluate the value that electricity technologies provide to the power system.

of storage (LCOS) can be useful to compare costs between different storage technologies and track how costs change over time, but they do not provide an apples-to-apples comparison with generation resources (Schmidt et al. 2019). Furthermore, more simple metrics such as LCOE and LCOS may not capture changing system costs over time that can impact future costs of charging. For example, as the generation mix shifts to include more low-cost-renewable energy, the cost of charging a storage device may decrease over time. Also, energy storage devices may be required to operate more often (i.e., with a higher number of cycles) as the demand shape and generation mix changes in the future. These types of trends may not be captured in a levelized cost metric. In addition to the cost of energy storage, project developers, utilities and end-use customers need to know how long a particular device is expected to last, what performance characteristics to expect over the lifetime of the device, and whether manufacturer warranties are available to mitigate the risk of equipment defects. These aspects are further discussed in Text Box 4.

See, for example, NREL's Annual Technology Baseline for projections of costs for energy storage as well as other electricity technologies (NREL 2020).

Table 4. Key Cost Metrics for Energy Storage Projects

Energy Storage Cost Metric [Units]	**Description**
Installed Cost [$/kW or $/kWh]	The installed cost is the total per-unit cost of an energy storage system, including all components, power conversion systems, labor, construction, and other "soft" costs. Installed system costs are represented as the cost of either power capacity ($/kW) or energy capacity ($/kWh). Costs for battery storage systems are often expressed as energy capacity costs ($/kWh) while costs for pumped storage hydropower, flywheels, and other mechanical storage devices are expressed as power capacity cost ($/kW) due to their longer durations. This metric is most useful for tracking how the cost of specific technologies changes over time or for comparing costs from different manufacturers or vendors. However, installed cost does not provide an apples-to-apples comparison across different storage technologies or between storage and conventional resources like natural gas turbines.
LCOS [$/kWh]	The LCOS metric represents the total cost of constructing, operating, and maintaining an energy storage system over its lifetime, expressed either in terms of cost per unit of energy capacity ($/kWh). Importantly, LCOS includes maintenance costs needed to keep the system performing as intended throughout its economic life. This is especially relevant for battery storage technologies that degrade as they are used. LCOS is most useful for comparisons between different energy storage technologies for the same application (Schmidt et al. 2019).

Text Box 5. Warranties and Energy Storage

The operating performance of an energy storage project, including aspects like response time and storage duration, may potentially deviate from what was expected by planners and developers. Such deviations in operating performance are influenced by a number of factors, including potential defects from equipment and component manufacturers, harsh environmental conditions beyond what the device was originally designed to handle, and improper operation or maintenance of the system. In these cases, well-designed warranties can help mitigate the technical and operational risks associated with energy storage. The World Bank's Energy Sector Management Assistance Program (ESMAP) provides an overview of the important considerations for warranties for battery energy storage systems, in particular for developing countries, which may face additional challenges (ESMAP 2020). A key consideration identified by ESMAP is whether warranties for all project components apply for the full intended economic lifetime of the project (e.g., 15 years for a grid-scale battery storage system). Warranties that expire sooner can lead to significant delays and costs in the case of a component failure, posing a risk to project developers and electric utilities. In some cases, because energy storage projects can include components from different manufacturers, a turnkey project provider such as an engineering, procurement, and construction firm will maintain the manufacturer warranties and offer a "back-to-back" warranty with a single point of contact for the entire project.

The remainder of this report is organized by the services that energy storage can provide at different levels of the electric grid. Section 5 will help prepare readers to identify opportunities, make decisions, and enable deployment for transmission-interconnected grid-scale storage systems. Sections 6 and 7 will do the same for distribution interconnected grid-scale storage systems and customer-sited BTM storage systems, respectively.

5 Is Energy Storage Appropriate for Transmission-Level Services in My Power System?

This section describes the various transmission-level services that storage can provide, and the key building blocks of the enabling environment for transmission-connected storage. Other sections of this guidebook will discuss key building blocks of enabling environments for distribution-connected and BTM storage, which may ultimately be able to provide these same types of transmission-level services as well.

5.1 Capacity Adequacy

Peaking capacity at the bulk-power system level is needed to maintain reliable electricity supply, or capacity adequacy, during normal operation and under extreme and emergency conditions. Power systems typically require additional peaking capacity above annual peak demand. This additional capacity is called the system capacity margin, planning reserve margin, or reserve margin, among other related terms. Traditionally, new conventional capacity is built to ensure that the system has enough reliable capacity to meet a long-term reserve margin requirement. However, energy storage can also help to support system adequacy and contribute to reserve margin requirements.

What to Consider

Bulk-power storage can be an alternative to conventional capacity like natural gas or diesel-fired combustion turbines. The decision to invest in storage for capacity services depends on a variety of factors:

Duration of Peak Demand. The duration of peak electricity demand periods determines how much energy capacity from a storage device is needed to reliably contribute to the reserve margin. In general, systems that have a shorter peak demand period can rely on shorter duration (2–4 hours) energy storage to provide peaking capacity. Power systems that have longer, sustained periods of high/peak demand (e.g., 4–6 hours) require storage resources with higher energy capacity (i.e., longer duration) to contribute to meeting peak demand. In general, shorter duration storage applications are less costly to build because less energy capacity is required. Thus, the shorter the duration of peak demand, the higher the likelihood that a storage investment will be economic relative to traditional peaking capacity.

Share of Solar PV in the Generation Mix. Studies show that increasing shares of solar PV in the generation mix change the shape of net demand, ultimately reducing the duration of peak demand.[8] Depending on the system's demand profile, as the share of solar PV increases, the change in the net demand shape can improve the ability for medium-duration (i.e., 4–6 hours) storage resources to provide reliable peaking capacity (Denholm and Margolis 2018).

Relative Cost of Storage Capacity. It is important to consider the cost of storage capacity relative to other grid solutions, including conventional fossil-fueled power plants and demand response programs, that can be used to meet peak demand.

How to Decide

If storage appears to be an appropriate choice for your system after broadly considering some of the above aspects, the next step would be to undertake a quantitative analysis to inform the decision. As a

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[8] Net demand is the total electric demand in the system after accounting for wind and solar generation, representing the demand that a utility or system operator must meet with other resources.

fundamental step, it is critical to define the evolution of capacity needs over time in a planning study, which often requires use of a CEM and/or PCM. Storage can be included in a capacity planning process as one option to serve peak load among other grid solutions, with the CEM itself identifying if storage is a cost-effective solution.

Text Box 6. Real-World Example: Battery Storage Projects Selected to Provide Peaking Capacity

In early 2021, two battery storage projects won bids to provide capacity services in the Independent System Operator (ISO) New England's annual Forward Capacity Market. The Forward Capacity Market is a capacity auction run by ISO New England to select cost-effective projects for meeting future capacity requirements. Projects selected in the 2021 capacity auction are scheduled to come online in 2024. Out of 2,525 MW of new resources that secured winning bids, 650 MW will be provided by two battery storage projects. Other winning bids include 170 MW of new demand response resources and 950 MW of new generation. More information about winning bids from the 2021 auction of the Forward Capacity Market is provided in this press release from ISO New England.

5.2 Load Shifting and Energy Arbitrage

Load shifting and energy arbitrage are two terms used to describe the process of shifting energy from one time of day to another during the operation of a power system. For example, excess electricity at night, when demand is low, can be stored until it is needed later during the day. Typically, stored energy is released during peak demand or during periods of high ramping requirements, which is also when electricity generation and delivery costs are often higher or at their highest.

What to Consider

Bulk-power storage for load shifting presents a unique opportunity to handle surpluses in VRE generation or inflexible baseload generation that cannot be turned off. The decision to invest in storage for energy shifting depends on:

Spread of Electricity Costs. Large differences between the daily valley and peak of electricity production costs (and prices if there is a wholesale market) provide opportunities for energy arbitrage (i.e., "buying low and selling high."). Power systems with relatively flat costs/prices, on the other hand, provide little opportunity for energy storage technologies to recoup costs from energy arbitrage.

Relative Cost of Storage Services Provision. The relative cost of energy storage compared to other grid flexibility options such as demand response is an important factor to consider. In some jurisdictions, rather than invest in new storage capacity, it can be more cost-effective to incentivize end-use consumers to shift the timing of their electricity usage. Incentives for demand shifting can be effective in places with large industrial loads such as automotive manufacturing, mining operations, metal processing, or commercial buildings like warehouses, which can shift the timing of their operations. Systems where most of the electricity demand comes from residential and small commercial building may be less suited for demand response programs because they require advanced metering, tariff design, and billing infrastructure, which leads to a higher cost per MW of demand response for smaller customers.

How to Decide

Because energy arbitrage is a unique grid service that is not provided by conventional power plants, conventional decision-support tools may not have "out-of-the-box" solutions to determine the value of energy storage for arbitrage services. Instead, a combination of CEM, PCM, and financial modeling tools can help inform planning decisions. Important inputs for this analysis include the cost of energy storage capacity (both power and energy), the typical hourly profile of electricity prices, and the mix of generating technologies that currently serve demand. The value of storage for energy arbitrage can capture both electricity price differentials (i.e., “buy low, sell high”) as well as avoided startup of conventional power plants (i.e., startup cost of gas-fired peaking plants). The quantitative analysis can provide insights about where, when, and what configuration of energy storage technology would provide sufficient arbitrage value to exceed the cost of the storage device. Another important input is the availability of demand response, including information about the maximum available demand response from industrial, commercial, and residential sectors. It is important to ensure the quantitative tools can adequately represent the evolving power sector landscape, to capture anticipated changes in electricity demand, costs of energy storage, availability of demand response, and costs of conventional technologies in the short, medium, and long term.

5.3 Transmission Upgrade Deferral

Energy storage systems can shift the timing of power flows in the transmission network to reduce loading on key transmission corridors, helping to avoid costly equipment failures and extending the life of existing assets. The ability of a storage project to provide transmission deferral services is highly dependent on the location where it is sited. For example, energy storage sited near the demand source, such as a city center or major industrial facility, can defer upgrades in the transmission corridor that connects “upstream” generation resources to the demand. The market and regulatory context is another important factor. Electric utilities must have the ability to include energy storage projects in their regulatory filings for transmission assets, and regulators may need to compel utilities to consider storage in planning processes.

In addition to deferring upgrades, energy storage systems can similarly increase the lifetime of existing equipment by reducing overall loading below the rated equipment carrying capacity, thereby reducing wear and tear on the equipment. Another related use case for energy storage can be to mitigate uncertainty for transmission upgrades. For example, in cases where near-term load growth is uncertain, a small energy storage investment can be a stopgap measure for a few years until there is more certainty about the need for a transmission upgrade, which can have a significant and quantifiable benefit. Using energy storage and other newer technologies to help defer upgrades to the transmission and distribution network is broadly referred to as NWAs. Utilizing energy storage for transmission or distribution upgrade deferral as a NWA solution or as a stand-alone project presents a unique opportunity to offset the need for costly conventional infrastructure investment, which may otherwise sit underutilized outside of the highest demand hours.

What to Consider

Cost of transmission upgrades and additions. In general, energy storage may be a more appropriate solution for transmission deferral in jurisdictions where transmission upgrades are very costly and where prospective new transmission corridors face right-of-way and land-use permitting issues, which may be time consuming and expensive to resolve.

Rate of demand growth. All else being equal, energy storage is well-suited to reduce transmission loading and delay transmission upgrades in areas of the power system with relatively low demand growth. A slower projected growth of demand may indicate that energy storage can delay a transmission upgrade for a longer period. For example, for a transmission corridor that needs increased capacity in the next year and is subject to 2% demand growth, a storage device that is sized at 4% of the existing capacity of the transmission corridor will be able to delay an upgrade for approximately 2 years. The value of deferring a large capital expenditure for upgrading the transmission capacity can be attributed to the storage device. With a higher rate of demand growth, the size of the storage device would need to be larger to defer the transmission upgrade for longer. For example, with 4% demand growth, the storage device would need to be larger, at 8% of the capacity of the existing equipment to defer an upgrade for 2 years, which may be cost-prohibitive compared to the value of deferring the transmission upgrade. Furthermore, because transmission congestion is localized in specific areas in the grid, it is important to assess demand growth on a localized level, as it relates to the specific transmission corridor that is congested or projected to become congested in the future.

Projected magnitude of overload of key transmission corridors. A small or modest projected overload of the carrying capacity of an existing transmission line may indicate that energy storage would be a cost-effective option for delaying major investments in transmission expansion.

Ability for storage to provide additional benefits. Transmission upgrade deferral in many contexts will only require the energy storage system to discharge in a relatively few number of hours in a given year, specifically those hours of highest system stress. This may allow for significant opportunities for the energy storage system to provide additional system services (see Section 3.3). Providing these additional services can lower the overall cost of utilizing the storage system for transmission upgrade deferrals, making it more competitive with traditional investments.

How to Decide

The value of energy storage for deferring transmission upgrades is tightly linked with the cost of storage, the cost of transmission upgrades, and the rate of load growth. Energy storage can be a cost-effective solution if it can substantially delay needed investments in the transmission network. However, in many cases, a transmission upgrade will be needed eventually. The decision to invest in an energy storage solution rests on the marginal cost savings that can be achieved from delaying the transmission investment. Different tools are used to evaluate this trade-off for different time horizons and geographic scopes. For a high-level assessment, scenario-based analysis using a combination of long-term capacity expansion and production cost modeling tools can indicate where and when energy storage investments can delay transmission expansion. For near-term and localized assessments, financial models that are commonly employed in regulatory proceedings to evaluate investment prudence can indicate whether an energy storage project is cost-effective, either for extending the life of specific transmission equipment or for deferring local upgrades.

5.4 Essential Grid Services

Because power systems must balance the supply and demand of electricity at all times, system operators rely on a range of services that help maintain a reliable and stable power system at time scales ranging from sub-seconds to several hours. These essential grid services (otherwise known as ancillary services) are provided by grid resources that can be preprogrammed for automatic responses or called upon by system operators to mitigate imbalances in supply and demand. Energy storage technologies outfitted with modern power electronics and control systems can be well-suited to provide various types of essential grid services. There are three major categories of essential grid services that energy storage can provide:

1. *Operating reserves.* Operating reserves are needed to maintain the supply-demand balance in the power system as demand changes throughout the day, during unexpected supply-side disruptions such as a transmission line outage, and during extreme weather events.
2. *Voltage regulation.* Also known as voltage support services, voltage regulation services help to maintain stable voltage levels on individual transmission and distribution circuits.
3. *Black start.* Black start is the process of restoring electricity service following a partial or total network outage. In the event of an outage, power plants and network equipment require a stable

source of electric power to return to normal operation. This is a basic requirement for all electric power systems.

What to Consider for Operating Reserves

Magnitude of operating reserve requirement. The total amount of operating reserves needed to maintain a reliable electric grid depends on a series of factors, including the size of the power system, the mix of customers being served, the sizes and types of generators that supply electricity, changing weather conditions, and other environmental conditions. In every power system, the amount of operating reserves needed at any given time is a fraction of the installed generating capacity. Because the requirement for operating reserves often can be filled by a handful of generating resources, opportunities for energy storage to provide additional operating reserves can be small. However, if demand growth is high and/or conventional plants are planned to be retired, energy storage may be a cost-effective source of new operating reserves capacity.

Duration of operating reserve requirement. Different types of operating reserves require different durations of response from participating resources, from several seconds to several hours. At the same time, different energy storage technologies have different durations that can make them more or less suitable for providing certain types of operating reserves. Pumped storage hydropower plants, for example, typically have multiple hours (e.g., 12 hours and longer) of energy storage capacity, meaning they are likely to be available when needed to provide longer-duration services. Battery energy storage systems, on the other hand, are historically more cost-effective for shorter-duration applications, although costs for longer-duration battery storage (e.g., 4 hours and greater) are declining rapidly.

Response time requirement. Like duration, different types of operating reserves require different response times from participating resources (i.e., the amount of time it takes for the resource to react to a system operator's command or automatic control signal). Unlike duration, which is largely driven by the cost of storage capacity, response time is typically limited by a technology's physical capabilities. Mechanical energy storage devices like pumped storage hydro and compressed air energy storage typically have longer response times (e.g., several minutes), while batteries and electrical devices can typically respond in less than one second. For certain frequency regulation services, a faster and more accurate response to control signals can help reduce system operating costs. In the United States, several jurisdictions are enabling grid resources to be compensated, in part, based on the speed of their response. ERCOT, for example, is implementing a new operating reserve product called Fast Frequency Response that requires participating resources to respond within just over half a second (Du et al. 2020). In other parts of the United States, FERC, through FERC Order 755, requires regional transmission system operators to explicitly reward resources for their speed of response in ancillary service markets (Order No. 755-A 2012).

What to Consider for Voltage Regulation Services

Local voltage regulation requirements. Stable voltage levels are primarily maintained locally on individual transmission lines and distribution circuits. Controlling voltage levels within acceptable bounds is essential to protect equipment and ensure reliable and efficient transmission of power. Energy storage devices can be used to help support stable voltage levels, which leads to reduced energy losses and prevents equipment from degradation. However, the location of an energy storage device will determine its ability to support local voltages. One consideration for siting an energy storage project can be current and future local requirements for voltage regulation, which can provide an additional source of revenue for the project.

What to Consider for Black-Start Services

Opportunities for additional energy storage services. Black start is a backup service that is, by design, seldom used. Traditionally, certain power plants in the network include backup diesel generators that are designed to provide black-start support. These systems are needed in the event of a network blackout when external grid power is not available. More recently, energy storage devices outfitted with grid-forming power electronics (known as grid-forming inverter-based resources) have been considered as an alternative to diesel-fueled black-start systems. An energy storage system that provides black-start support to a power plant can also be used to provide other grid services (see e.g., Sections 5.1–5.4), including energy shifting, peaking capacity, and frequency regulation. Without access to revenue streams from multiple services, it may be cost-prohibitive to dedicate an energy storage device solely to provide black-start support.

How to Decide

Various power system analyses and tools can be used to evaluate whether energy storage is a cost-effective source of essential grid services compared to conventional resources like fossil-fueled power plants and network equipment. Simulations of power system operations with production cost modeling tools help determine if and how much bulk-power energy storage can contribute to longer-duration operating reserves. Power Flow Models are used to assess how energy storage devices contribute to system stability through short-duration operating reserves and voltage regulation. For black-start services, detailed power flow modeling and testing is needed to determine whether an energy storage device can reliably and safely provide black-start support to specific generators in the network.[9]

Text Box 7. Real-World Examples of Storage Providing Transmission-Level Services

Battery Storage Project Provides Essential Grid Services. The Hornsdale Power Reserve in South Australia is a lithium-ion battery system that provides transmission congestion reduction, frequency control, and voltage support services. The initial phase of construction with 100 MW/129 MWh of battery storage capacity was completed in late 2017. An additional 50-MW/64.5-MWh expansion was completed in September 2020, increasing the project's power capacity by 50% and maintaining the 1.3-hour duration. Although the project is co-located with the 360-MW Hornsdale Wind Farm, the battery system operates independently based on grid-wide needs. According to project owner Neoen, the system helped reduce electricity costs for consumers by $116 million in 2019 by lowering the price of frequency control services in the South Australia region of Australia's National Electricity Market. More information about the project is available at the Hornsdale Power Reserve website.

Successful Black-Start of a Gas Turbine With Energy Storage. In February 2020, GE demonstrated the first successful black start of a heavy-duty gas turbine using energy storage. A 7.4-MW lithium-ion battery storage system at the Perryville Power Station in Louisiana in the United States was used to black start a 150-MW simple cycle gas turbine. More information is provided in this press release.

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[9] The black-start capability of energy storage and other inverter-based resources is an active area of research (Jain et al. 2020).

5.5 Building Blocks to Enable Provision of Transmission-Level Services

Clear Technical Interconnection Processes and Rules: Fundamentally, to provide the services listed above, energy storage projects must have a pathway to connect to the power system in a safe and orderly manner. To do this, there must be a clear and predictable interconnection *process* by which energy storage developers can apply for interconnection to the utility system. Central to this process is clear technical requirements describing the desired performance and behavior of the energy storage system under various operating conditions, as well as clearly defined technical screening practices for evaluating interconnection applications.

Clear Participation Rules: Foundationally, energy storage devices need a participation framework for operating and seeking remuneration within the power system. To that end, various market rule changes may be required for energy storage resources to be able to participate. Such modifications would seek to ensure the eligibility of storage to participate in the power system in a way that recognizes the unique technical and operational characteristics of the resource class. Furthermore, policymakers and regulators may have to clearly define the allowable investment, ownership, and remuneration models (i.e., "business models") for storage projects in their jurisdictions. What these changes look like in practice, however, will depend significantly on the market context. For settings with wholesale energy markets, regulators and market operators likely need to collaborate to identify and implement changes to a variety of market rules.[10] For vertically integrated and/or single-buyer markets, centralized utility procurement processes are often the "point of market entry" for many power system resources; thus, modifications to competitive procurement practices to include storage may be the relevant point of intervention for policymakers and regulators to consider.

Ability for Storage to Seek Fair Remuneration: Modifications to policy, market, and regulatory frameworks are often required in order for storage to realize its full economic value and seek remuneration for provision of multiple system services. Changing various aspects of these frameworks can ensure storage resources can be fairly compensated for the range of flexibility services they are technically capable of providing (or at least some portion of those services). For settings with wholesale energy markets, it may be necessary to create specialized market-based rules that allow storage resources to "stack their services" and be remunerated for the incremental benefits of providing multiple grid services simultaneously, while also avoiding double-counting of services. For vertically integrated and/or single-buyer markets, policymakers may need to ensure that storage is: (1) fundamentally considered in planning exercises; (2) considered in such a way in planning that its multiple value streams can be quantified; and (3) a stable, value-reflective compensation for these multiple values streams is offered during infrastructure procurements.

Regulatory Support for Pilots: While storage resources are in many respects exhibiting a higher degree of commercial readiness in recent years, many utilities are nevertheless in a phase of "familiarization" with these novel resources. The technical uses for storage to support power systems are well-known in theory, but in practice they are still being tested and explored by utilities. Furthermore, understanding how these novel resources can be incorporated into a utility's portfolio of assets, business model, and planning and procurement processes provides an additional layer of complexity to this familiarization process. Therefore, facilitating utility pilots for energy storage resources may be an important tool to

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[10] In the United States, for example, FERC issued Order 841 in February 2018, which directed ISOs and regional transmission organizations to open wholesale energy, ancillary service, and capacity markets to energy storage resources (FERC 2018). This order is expected to enable an increase in the ability of batteries to participate in electricity markets across the United States.

promote utility familiarization and ultimately support the procurement of system flexibility services from these resources. Some pilot projects may require ratepayer financing to pursue. Others may simply need regulatory approval for a utility to enter into a contract with a private storage developer to provide flexibility services, and/or regulatory exemptions to connection codes in the event that storage interconnection requirements are not yet developed. In any case, regulatory requirements to transparently monitor the technical and economic performance of the pilot, and publicly disseminate learnings to the extent feasible, are typically a good practice.

Text Box 8. Should Batteries Be Co-Located With Generation Resources?

A growing trend in the power sector is the concept of co-located storage projects with power plants, representing a hybridized combination of generation and energy storage at the same location. There are natural synergies to coupling power plant technologies such as solar PV, wind, or even natural gas combustion turbines with energy storage. For example, natural gas plants and other conventional generators may benefit from reduced wear and tear, as the battery is dispatched to avoid startups, shutdowns, and excessive ramping. Additional benefits of co-locating resources for wind and solar PV include the potential for reduced project costs as many of the same components (such as an inverter) can potentially be shared as well as reduced costs from shared construction, siting, and permitting. Furthermore, for solar PV, storage may be able to capture energy from the generator that would otherwise be wasted due to undersized inverters relative to the size of the generator (known as "inverter clipping") (Gorman et al. 2020). As well, across all technologies, if storage is co-located at an existing power plant, it may be possible to use the balance sheet of the plant to secure financing for the storage device.

However, co-location may have several significant drawbacks. First, as the energy storage system is behind the same point of interconnection as the generator, it may be restricted in its operation, which can reduce the value it can provide to the developer and power system. The level of restrictions that a storage system will face depends on how the storage system is ultimately coupled to the generator as well as the size of the shared interconnection. Second, the location of optimal siting for wind and solar PV may not overlap with areas where energy storage can provide the most value (e.g., areas with good solar and wind resources may not overlap with points of high system constraint). Co-locating generators and storage may ultimately result in sub-optimal compromises in location relative to independently sited resources. Finally, many of the operational benefits of co-location (e.g., more dispatchability and more predictable exports to the grid) can be ensured regardless of whether the resources are co-located (Gorman et al. 2020).

6 Is Energy Storage Appropriate for Distribution-Level Services in My Power System?

Energy storage connected at the distribution level (i.e., "in front of" customer meters), can provide services both to the distribution system as well as to the transmission system. This section will focus on distribution-level services but will also offer general recommendations to enable and evaluate the provision of transmission-level services from distribution-interconnected energy storage resources.[11]

Text Box 9. Real-World Example: Meeting Policy Objectives and Peak Demand With Energy Storage.

As part of the Oakland Clean Energy Initiative, (OECI) the utility Pacific Gas and Electric (PG&E) and the community choice aggregator East Bay Community Energy (EBCE) in California have begun procuring over 43 MW of energy storage with two projects, both lithium-ion systems connected at the distribution level. The OECI seeks to meet the peak demand needs of the Oakland area with energy storage, helping to offset local fossil generation from the jet-fueled Oakland Power Plant, which has been a significant source of local air pollution. These storage systems help PG&E and EBCE ensure sufficient transmission capacity for its customers' peak demand while also meeting storage procurement targets (California's AB 2514) and clean energy and environmental ambitions. For more information, see the PG&E website for the project.

6.1 Distribution Network Upgrade Deferral

As with the transmission system (see Section 5.3), distribution upgrades are periodically needed to ensure sufficient distribution capacity is available in a given segment of the distribution system to deliver power to meet all demand in all hours of the year. These upgrades might be triggered by overall demand growth, changes in demand patterns or aging or faulty equipment. Historically, distribution utilities have focused on "wire-only" solutions, replacing existing equipment with traditional investments such as distribution lines, substations, and transformers. More recently, however, some distribution system operators, often under directives from policymakers and regulators, have begun considering non-wires alternatives (NWAs) as well. These can be particularly valuable in space-constrained areas, such as on a feeder in a densely populated urban environment.

What to Consider

Local demand profiles and forecasted demand growth. The shape of the aggregate demand profile at a given distribution node will have a strong influence on which investment is most appropriate to address upgrade needs. Many cost-effective energy storage systems are characterized by limited durations in the timescale of several hours, with costs increasing as storage duration requirements increase. Thus, it is typically less expensive to defer distribution upgrades with storage when the demand on that portion of the system is higher for relatively shorter time frames, such as demand spikes caused by electric vehicle charging infrastructure. This is also true of demand response programs, which may only be able to reliably reduce demand during a relatively short time frame. Flatter profiles characterized by longer periods of demand in excess of existing distribution capacity may be more appropriately addressed using traditional distribution capacity upgrades or through energy efficiency measures that may be able to flatten overall demand. Low forecasted demand growth indicates that energy storage can help address transmission constraints for more time before upgrades are needed (see Section 5.3 for more information

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[11] The subsequent section will discuss customer-facing services from resources interconnected at the distribution level "behind" a customer's meter.

on the connection between load growth and energy storage suitability). Adequately forecasting load growth on a distribution system, taking into consideration the effects of electrification and other DER adoption on future load profiles, is a critical step in ensuring a no-regrets portfolio of investments.

Siting constraints. Compared to addressing capacity constraints on the transmission system, conventional distribution upgrades are far more likely to suffer from acute siting constraints, such as limited land area to site a project or proximity to populations that may resist development. In these cases, conventional distribution upgrades may be less feasible than NWAs, which might include distribution-interconnected storage, distributed generation, or energy efficiency.

Response reliability. Many NWAs rely on the behavior of assets of individual customers as opposed to assets owned and controlled by the distribution system operator. Customer behavior and asset operation are typically influenced either indirectly through retail tariffs or directly through customer programs. While such approaches allow for cost sharing of assets with customers, unless certain behaviors can be guaranteed (e.g., demand reduction for a set number of hours during peak periods), these approaches may not be able to reliably reduce the need for distribution system upgrades. In comparison, distribution-interconnected energy storage has a much more predictable and reliable response that is typically controlled by either the distribution system operator or a sophisticated third-party developer.

Storage technology costs. As with other services, it is important to consider the associated costs of storage technologies against other alternatives. The cost of deferring distribution system upgrades with storage will vary with the power and energy (i.e., duration) capacity of storage needed, as well as other factors. Issues including siting constraints or contracts to guarantee energy availability from storage (for NWA approaches where the assets are not owned by the distribution system operator) will also influence the costs that must be considered. Finally, costs over the entire lifetime of a project should be compared to that project's utilization. Many traditional distribution upgrades are typically made several years in advance to accommodate forecasted demand growth and are built primarily to meet peak demand during a relatively limited number of hours in the year. Consequently, such assets may sit underutilized for a majority of their lifetimes, and this should be taken into account when comparing to a storage investment.

How to Decide

If energy storage seems like a viable option after initial consideration, a combination of load forecasting and distribution network modeling for the circuit in question can help answer key questions, such as: how many hours out of a given year will local demand exceed existing capacity? What is the longest consecutive period that energy storage might need to meet local demand to avoid overloading existing infrastructure? Answering these questions through forecasting and modeling can inform the operational characteristics of the energy storage system (or a portfolio of NWA solutions including energy storage) needed to defer distribution infrastructure investments, which will inform how much the energy storage system would cost. Once this cost is known it can be compared against the costs of an equivalent investment in traditional distribution infrastructure (e.g., reconductoring lines, upgrading transformers). It is important to note that a distribution-interconnected storage system may only need to provide this service in select hours of peak demand in a given year and could potentially provide additional services the rest of the time, helping to offset initial costs.

Text Box 10. Real-World Example: Deferring Distribution Upgrades With Mobile Storage

As part of the Reforming the Energy Vision initiative, ConEdison, a distribution utility in New York, contracted with a battery developer for up to 4 MWh of mobile energy storage units to help alleviate congestion in select areas. The storage units will be operated to defer distribution upgrades for several years before being relocated to other constrained portions of the grid, enabling ConEdison to wait until demand has grown to better utilize new capacity from a distribution upgrade. The mobile storage units will also be able to bid for services in the wholesale market to earn additional revenues. In a unique business model, the mobile energy storage systems will be leased to the utility, allowing ConEdison to save even more while also enabling value stacking activities. For more information, see the New York REV Connect website for demonstration projects.

6.2 Distribution Voltage Support and Power Quality

Distribution utilities are tasked with providing reliable and high-quality power within specific constraints, including acceptable voltage, current, and frequency levels. Ensuring that delivered power meets power quality standards is critical, as most electrical equipment can only reliably and safely operate within a limited band of voltages, currents, and frequencies. Broadly speaking, deviations in frequency are caused by system-wide imbalances between demand and supply (e.g., a centralized generator or transmission line tripping offline), while deviations in voltage or current are more local in nature. Local power quality issues can be caused by problems with utility equipment or certain customer activities or equipment (e.g., welding, escalators, startup of heavy machinery). Fast-acting energy storage can help compensate for system-wide or local issues by quickly injecting or absorbing power to maintain voltage, current, and frequency within acceptable levels.

What to Consider

Energy Storage Technology Costs. Given there are already established solutions for distribution voltage, current, and frequency excursions, the primary consideration for deciding on storage is comparing its technology costs with traditional approaches. While energy storage costs may exceed these more traditional solutions, if the storage system is allowed to provide multiple services, storage may ultimately prove to be the most cost-effective solution.

Reason for voltage excursion or power quality issue. Voltage, current, and frequency excursions can be caused by several distinct issues such as changes in load patterns or faulty equipment. The most sensible choice for voltage support will be influenced by the underlying causes of the excursions. If voltage excursions are caused by high demand (or a quick ramp up in demand) in a select number of hours, energy storage may be an ideal solution as it can shift that demand to other hours, helping defer more expensive traditional upgrades. If DER exports are causing power quality issues, such as increasing voltages beyond acceptable tolerances at the end of long distribution feeders, restricting exports from these DER at certain times may be appropriate. Implementing the latest international standards for DER interconnection and grid operability (such as IEEE 1547-2018) may be an alternative solution with less negative impact to adopting customers, although adopting such standards may be administratively burdensome. In other situations, power quality issues may be caused by faulty equipment that can be readily replaced or repaired. Finally, customer activity may cause power quality issues. Many jurisdictions already have measures in place requiring larger customers to take steps to ensure their activities do not affect local power quality, including through the imposition of financial penalties.

How to Decide

If changing load patterns or increases in distributed generation are causing, or are forecasted to cause, voltage excursions on a circuit, power flow modeling of the circuit can help determine the operating characteristics (reaction time, energy and power capacity, duration) of an energy storage system necessary to address the voltage issue. Energy storage can then be compared on a price basis against more traditional investments.

6.3 Distribution Loss Reduction

When delivering energy from a generating resource to the site of demand, the energy produced suffers losses as it travels through transmission and distribution equipment, with more losses estimated to occur in the distribution system than the transmission system (Jackson et al. 2015). These losses are influenced by several factors, including the distance the power must travel, the material through which the power must travel, and the voltage level at which it travels. There are several ways storage can potentially reduce losses on the distribution system which include but are not limited to: reducing the distance power must travel between load and generation; managing load patterns on the system; and managing voltage on the system to improve delivery efficiency.

All else being equal, the shorter the distance the power must travel, the less power is lost. Distribution-connected storage could reduce the distance power must flow by enabling excess energy from distributed generation to be locally stored and later delivered to serve demand. However, energy storage suffers from round-trip efficiency losses that must also be considered. The amount of power flowing through the system also influences losses, with more power associated with higher losses. Using storage or demand response to shift demand from higher demand periods to lower demand periods can therefore help to reduce losses.

What to Consider

Source of losses. As described previously, there are different drivers of losses on the distribution system that can at times appear simultaneously, including due to the distance the power must travel and demand patterns. When determining whether storage is the best solution to reduce losses, the first step is to identify the primary source of losses, which can help to better inform which solution might be best. Some losses, such as theft, are not technical in nature and can be addressed through better regulation, monitoring, and enforcement. However, if the sources of losses are technical in nature, utilities can consider storage alongside more traditional approaches such as increasing the size of lines or having them reconductored, siting distribution transformers closer to load centers, or rebalancing load across phases, among other options.

Technology costs. Applicable solutions should be compared on a cost-benefit basis. For example, if losses can be avoided by better managing load on a line, the upfront costs of storage should be compared with the operational savings over time of reducing losses, including the value of energy saved and the value of extended equipment life by investing in storage. This type of cost-benefit analysis could also be performed for a demand response program (which may be an alternative to a storage investment to reduce losses), and then those results can be compared with storage to identify the most cost-effective solution.

Round-trip efficiencies. One important consideration when seeking to use storage to reduce distribution system losses is the efficiency losses inherent to the energy storage technology. Many storage technologies have high round-trip efficiencies, such as lithium-ion, but others may have considerably lower efficiencies, like flow batteries. Round-trip losses should be considered alongside other technical operating parameters, like duration, of the storage technology considered.

How to Decide

Distribution system modeling that captures local distributed generation, distribution topography (e.g., what equipment is present, how long are the lines, etc.), and demand patterns can help determine the losses experienced within a given segment of the distribution system. Modeling can also capture how an energy storage system dispatched to reduce losses would operate and could determine the share of energy that would be lost due to the round-trip inefficiencies of the storage system.

6.4 Improved Resilience

Resilience refers to the ability of power system planners and operators to "anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions to the power sector through adaptable and holistic planning and technical solutions" (Stout et al. 2019). As opposed to reliability, which typically focuses on routine events with shorter timescales and smaller impacts, resilience is focused on low-probability, high-risk events with large-scale and long-duration consequences (Anderson et al. 2020). While bulk power system operators have historically focused on reliability, in recent years growing attention has been paid to resilience at the distribution level, especially in response to significant natural disasters caused by climate change and growing cybersecurity threats. In the face of these growing threats, having resilient distribution systems will prove critical to ensuring critical infrastructure can still function as the power system recovers after severe events, reducing risks to customers, and more broadly minimizing negative impacts to the economy. Distribution-connected energy storage can play an important role in improving power system resilience by providing backup power to isolated sections of the network, extending the use of distributed generators, and by bringing the power system back online after a blackout. Applying storage in such microgrid applications can help ensure critical infrastructure is available during emergency conditions, such as a hospital during and in the aftermath of a natural disaster. Storage and other distributed power system assets within microgrids, when not providing backup power during outages, may be able to provide additional services to the power system during normal operations, such as reducing peak demand, earning additional revenues to offset initial expenditures. Evaluating energy storage as a source of power system resilience can be complicated by difficulties in evaluating the actual ratepayer or social benefits of improving resilience.

What to Consider

Nature of threat. Potential threats to the power system come in a variety of forms and with a variety of probabilities of occurrence, from natural disasters such as hurricanes to human-made threats such as cyberattacks. Energy storage at the distribution level is better suited to address potential interruptions of power delivery from the transmission system (e.g., fallen power lines or impacts to centralized generators) than it is to avert cyberattacks. Understanding the nature of the likely threat and weak points within the power system can help planners decide whether energy storage systems may be merited, or if undergrounding certain power lines or other reinforcement efforts could suffice.

Duration. For resilience services such as providing backup power to a subsection of the power system, the duration of the storage system is important to consider, particularly if the storage system is providing services to critical infrastructure such as hospitals or emergency shelters. Electricity demand from critical infrastructure is often referred to as "critical loads." The duration of storage solutions should be compared with the anticipated power and energy needs for critical loads, which will also depend on the expected outage duration (see "Nature of threat" above). Some duration-related concerns can potentially be offset by pairing energy storage with distributed generation (see "Associated generation" below).

Associated generation. Resilience events can last longer than most typical energy storage durations and therefore storage systems designed to offer resilience services are often connected to a separate generation resource to supply energy for charging.[12] During resilience events, access to the grid will potentially be compromised, otherwise limiting energy storage's contribution to local resilience. Pairing energy storage with distributed generators (such as solar PV, wind, or diesel) can improve both the storage *and* the generator's potential to address local energy needs for the duration of the resilience event.

Multiple-use applications and state of charge. Storage is capable of providing multiple services across many different stakeholders. When storage is contracted to provide essential resilience services, however, care should be taken to ensure additional service provision will not interfere with those resilience services. For instance, if a battery is contracted to provide backup power in case of a contingency event but also allots some of its capacity to bid into the wholesale market to sell energy, without interventions it is possible that the battery will not have enough stored energy to provide its contracted resilience services at full capacity. In California, the California Public Utilities Commission developed a series of rules to ensure batteries contracted for reliability and nonreliability services are always be able to provide some degree of reliability services when called upon (CPUC 2018).

Energy storage technology costs. As always, energy storage should be considered against relevant alternatives, considering upfront costs as well as the quality of service (and duration) that storage's unique operating characteristics can provide.

How to Decide

Determining which approach for meeting power system resilience needs is a matter of comparing the costs of each approach and the value that a given approach can provide in terms of improved resilience. Evaluating the benefits of improved resilience can be significantly more challenging than estimating costs and depends on social and economic factors that are highly context dependent. This is further complicated by the nature of the threats themselves, which occur infrequently and may be hard to predict and have wide-ranging impacts. For more information on determining the risk associated with contingency events and the value of increasing resilience in the face of these events (as well as storage's role in providing resilience), see the Resilient Energy Platform.[13]

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[12] Some energy storage technologies can produce their own electricity. Hydropower plants including some pumped storage hydropower have natural water inflows that enable on-site electricity generation. However, other storage technologies including all types of battery storage do not produce electricity and must rely on external sources of energy for charging.

[13] The Resilient Energy Platform and associated Planning Guidebook can be found here: https://resilient-energy.org/.

Text Box 11. Real-World Example: Combining Resilience Provision With Other Grid Services

Commissioned in 2015, Green Mountain Power's (GMP's) Stafford Hill Project in Vermont provides a number of services, including: (1) resilient backup power to a public emergency shelter; (2) reducing GMP's peak demand, thereby saving money on charges from the regional transmission operator and capacity market; (3) offering frequency control and demand response services to the wholesale market; and (4) performing energy arbitrage on the wholesale market for GMP. The 4-MW/3.4-MWh system consists of lead-acid and Li-ion batteries and is paired with 2.5 MW of existing solar PV panels, further helping GMP integrate distributed generation resources. The system is estimated to have a payback period of approximately 8 to 10 years, and in a single 1-hour period is able to save GMP roughly $200,000 per year in capacity charges by reducing GMP's demand on the wholesale market. For more information on the project see Schoenung et al. (2017) and the Green Mountain Power website for the project.

6.5 Building Blocks to Enable Provision of Distribution-Level Services

Regardless of the service in question, there are several key building blocks that decision makers can put in place to facilitate the fair and effective consideration of energy storage alongside more traditional (or other, newer) options for provision of that service.

Regulatory support for pilots. Despite energy storage's growing prevalence in the power system, many distribution system operators may still be unfamiliar with the technology compared to more traditional assets. Even if the technical capabilities of energy storage are well understood, achieving the full potential of energy storage may require changes to operating practices or regulations that may only become apparent in practice. Policymakers and regulators can encourage familiarization with storage through the development of pilot projects. These projects allow stakeholders to experiment with various technical, operational, and regulatory options to incorporate energy storage in a contained environment. Such pilot projects will be particularly important when determining how to use distribution-level assets to meet the needs of both the distribution system *and* the transmission system. In Maryland, policymakers and regulators directed each investor-owned utility in the state to develop two 10-year energy storage pilots, with a focus on experimenting with different ownership models. These pilots will help regulators determine which ownership models can provide the most benefit to ratepayers at least cost and can help utilities familiarize themselves with providing services with energy storage they own or procuring it from third parties.

Technical regulations specifying storage capabilities and behavior. Integrating energy storage into the distribution system and accessing its full value will require technical regulations that ensure reliable, predictable behavior from the asset during both normal operations and in response to contingency events. Such regulations could cover myriad topics from communication capabilities, level of observability over the storage system for system operators, and various operational characteristics such as minimum response times to signals from a system operator. Although existing standards may adequately cover most of the technical requirements, energy storage systems that provide power to both the distribution and transmission system may need additional review and capabilities. For instance, the New York Independent System Operator has developed rules for distributed systems (both in front-of-the-meter and BTM) who wish to provide services to customers, utilities, *and* the wholesale market. These rules entail things such as compensation for service provision, telemetry obligations, and response times (Lavillotti and Smith 2019). Energy storage has many unique characteristics, like exceedingly rapid response times and ramp rates, that may take additional requirements to fully utilize.

Addressing nontechnical barriers. In addition to technical barriers, accessing the full value of energy storage can provide may rely on removing nontechnical barriers around ownership of the system and value stacking. These issues are particularly pressing for energy storage, as the high upfront capital costs of energy storage systems may necessitate providing many different services across many different customers. For storage systems developed and owned by third parties, the burden of identifying customers across different stakeholders may prevent the storage project from becoming economically viable. For storage systems owned by and providing services to regulated entities, concerns over cost sharing among different customers, who may be benefiting to different degrees from the storage system, may be a concern. Existing regulation in some jurisdictions may also expressly prohibit regulated entities like transmission or distribution system operators from owning or operating a generation facility, which storage may qualify as when providing specific services. In general, energy storage may face barriers due to its unique ability to act as both generation and load and serve multiple stakeholders, which may require adjustments to existing regulation developed for assets that were only either generation or load (see Text Box 3).

Changes to existing planning and operating practices. As a new and relatively unique power system asset, energy storage may often be overlooked in planning and operating practices for both distribution- and transmission-level exercises. In addition to pilot projects, decision makers can explicitly require such stakeholders to consider energy storage in their normal planning exercises or for various power system services. Such requirements can help make sure more novel approaches to power system needs are considered on an even playing ground with more traditional investments. This may be particularly important for storage assets on the distribution system providing services to the bulk power system. Such requirements also ensure that over time distribution and transmission planners develop both familiarity with storage assets and tools and practices for better evaluating their potential for meeting power system needs.

Regulations to enable business model innovation. Fully accessing the value that energy storage can provide both to the transmission *and* distribution system may require innovations in business models surrounding energy storage. This is particularly important given the high upfront capital costs for energy storage, as these systems must be able to provide the most services possible to recuperate their initial cost. New business models can remove barriers to providing services to various stakeholders, including groups of distribution customers, distribution utilities, and power system operators. Such business models can also innovate how capital is collected for the initial investment across multiple stakeholders as well as how these costs are ultimately recouped from various stakeholders benefiting from the storage system. Existing regulations may implicitly or explicitly bar energy storage from seeking compensation for the full range of services of which it is technically capable of providing. Existing regulations may also require a single owner and beneficiary of an energy storage system. Making regulations more technology agnostic, explicitly allowing energy storage to provide multiple services, and allowing innovative shared ownership approaches can help improve the viability of energy storage and increase its value to the power system.

7 Is Energy Storage Appropriate for Customer-level Services in My Power System?

BTM energy storage systems, most commonly in the form of stationary electrochemical batteries, are connected behind the utility meter and typically located on the consumer's premises. Commercial, industrial, and residential consumers may consider deploying BTM storage to minimize electricity bills (e.g., for demand charge management or increased utilization of on-site renewable energy production), secure a continuous supply of electricity (i.e., backup power during outages), and/or ensure power quality for critical equipment on-site. Moreover, BTM storage can provide upstream grid services to stakeholders at all voltage levels, provided there is a framework for participation, storage energy flows are not restricted to disallow exports, and sufficient communication infrastructure is in place to send control signals and measure responses. Rules and regulations surrounding compensation for grid services play a role in allowing and rewarding BTM batteries to provide upstream grid services. These services can include many of the services mentioned in previous sections such as deferring or avoiding investments in network infrastructure, provision of peaking capacity, or load shifting to help better balance supply and demand.

Unlike with systems interconnected at the transmission level or distribution level "in front of" the customer meter, BTM storage systems are typically owned and operated by customers themselves. Customers typically choose when and where to deploy BTM storage, not utilities. Due to the decentralized nature of decisions to invest in BTM storage, decision makers can instead focus their efforts on enabling customer deployment and potentially creating incentives to align the interest of consumers with the broader power system. This section begins by exploring the key considerations for policymakers and regulators as they decide to what extent they wish to invest institutional resources in enabling BTM storage. The section thereafter outlines the primary drivers of BTM storage adoption and then concludes by discussing the institutional building blocks for facilitating BTM storage adoption.[14]

7.1 Options for Decision Makers to Enable BTM Storage

Decision makers have a few options to consider as they decide how to invest resources and institutional effort in the development of frameworks to enable BTM storage. Although the decision to install BTM storage is not centralized, decision makers can enable interconnection and potentially guide customer decisions in a way that can also support grid needs through appropriate policy design.

As decision makers consider the level of institutional effort they wish to invest in creating participation frameworks for BTM storage, there are three sequential and increasingly complex undertakings that can be pursued. These are:

1. **Enable Interconnection**: Decision makers can work to enable the safe and orderly interconnection of BTM storage resources in a systematic and "future-proof" manner.
2. **Enable Implicit Service Provision**: Decision makers can build on interconnection efforts by also designing economic signals for customers to adjust the operation of their BTM storage resources

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[14] This section features a distinct structure and set of objectives relative to the other sections of transmission- and distribution-interconnected storage to reflect the fact that electric sector decision makers, rather than directly making deployment decisions, are attempting to influence adoption of and, at times, operation of storage systems invested in by retail customers.

in a manner that benefits the power system. This is chiefly accomplished through DER compensation schemes and retail tariffs.

3. **Enable Active Service Provision**: Decision makers can also pursue efforts to enable direct utility or third-party control over customer-sited BTM storage resources to enable active service provision to the power system.

The following three subsections discuss these options in more detail.

7.1.1 Enabling Interconnection of BTM Storage

Designing clear interconnection standards and a streamlined interconnection process is a foundational step toward BTM storage market development. Decision makers will ultimately dictate whether a customer is allowed to deploy and interconnect BTM storage through the development of rules and regulations that allow the safe and orderly interconnection of BTM storage. In an ideal world, interconnection frameworks can be designed in a "future-proof" manner that avoids placing arbitrary restrictions on ownership, system sizing, or charging/export behavior to allow for DER market developments in the future.

7.1.2 Enabling Implicit Grid Service Provision

Implicit approaches to grid service provision rely primarily on sending economic signals to customers to both encourage adoption and adjust the operation of their systems in a manner that benefits the power system. For example, a time-of-use electricity tariff can encourage customers to avoid consuming energy from the grid during periods of grid congestion, low energy availability, and/or high energy prices. In general, these approaches can empower customers to make energy decisions that are both good for their energy bills and good for the power system.

Designing compensation mechanisms to incentivize more "grid-friendly" behavior must take several factors into consideration, including the ability of customers to understand and meaningfully respond to price signals. Typically, more cost-reflective retail tariffs are used to incentivize grid-friendly behavior; however, cost-reflective tariffs tend to be more complex, and some customer may be poorly equipped to adequately respond to them. In many jurisdictions, more complex tariffs have been preceded by educational outreach efforts and grace periods which allow customers to see what their bill *would* have been under the new tariff, while continuing to pay under the previous tariff.

While less capital- and effort-intensive than facilitating active approaches (see below), implicit service provision approaches may still require significant institutional effort to design and implement, from the tariff design effort to the educational efforts necessary to prepare adopting customers to utility administrative efforts to collect metering data and calculate bills using more complex tariffs. Additionally, investments in advanced metering infrastructure will likely be required to enable billing for more complex tariff designs.

Text Box 12. Real-World Example: BTM Program Supports Customer Needs and Grid Needs
Developed for BTM solar PV systems paired with energy storage, and requiring inverters and advanced metering technology, Hawaii Electric's Smart Export program drives customer behavior by compensating customers with export credits outside of peak-solar hours. The voluntary Smart Export program provides an electricity tariff that incentivizes participating customers to shift the timing of solar energy exports to evening, night, and early morning hours. Exports between 9 a.m. and 4 p.m. are not compensated. Participating customers receive a monthly bill credit for qualifying energy exports, which can offset the cost of a BTM energy storage system. Additional information about the program is available on the Hawaii Electric website.

7.1.3 Enabling Active Grid Service Provision

Active grid service provision relies on sending control signals directly to BTM storage devices to directly control operations, often in exchange for a market-based or regulated compensation. This approach relies on additional communication and control infrastructure to send a signal and measure the system's response. As an individual storage system is unlikely to meaningfully impact power system operations by itself, many systems in the same area on the power system are typically *aggregated* together. That is, the systems are sent signals and responses are measured to coordinate their total response such that they act as a single *aggregated* grid asset with a meaningful impact on power system operations.

The cost of additional communication infrastructure combined with associated costs from monitoring and coordinating these systems can be significant. However, active approaches can achieve a very accurate response as they are not dependent on customers' behavior. Aggregating BTM storage systems has grown in popularity as storage deployment has increased, and several jurisdictions have piloted successful programs that utilize distributed storage systems to meet peaking capacity needs, such as described in the Green Mountain Power example, or to provide grid services as outlined in the Australia Virtual Power Plants example. In addition to upfront costs, aggregation may face additional barriers such as regulatory uncertainty and difficulty coordinating multiple stakeholders. Decision makers can help overcome these barriers by explicitly allowing aggregation and developing novel business models (see "Regulations to Enable Business Model Innovation").

Text Box 13. Real-World Examples of BTM Storage Providing Upstream Grid Services

Interconnected BTM Storage Systems Help Reduce Peak Demand

As temperatures soared in the summer of 2018, Green Mountain Power's network of BTM energy storage resources reduced demand on the grid to offset more than $600,000 in costs for customers. About 500 individual BTM storage devices were operated as a single aggregated unit to achieve a reduction "equivalent of not burning 1,078 gallons of gasoline" according to Green Mountain Power. More information is provided in this Green Mountain Power news release.

BTM Solar-Plus-Battery Virtual Power Plants

The Australian Renewable Energy Agency has funded several Virtual Power Plant demonstrations and projects that aggregate thousands of BTM solar and battery installations to provide upstream grid services like frequency control and voltage support, while also rewarding participating customers through direct payments or bill credits. More information is available at the Australia Renewable Energy Agency website.

7.2 Drivers of BTM Storage Adoption

This section focuses on the distinct services that BTM storage can provide to end-use customers. Understanding the major drivers of BTM storage can help decision makers design programs that facilitate the adoption and operation of BTM storage to provide services to customers and the grid and also meet clean energy policy objectives.

7.2.1 Customer Bill Savings

Customer bill savings is a primary driver of investment in BTM storage, especially by commercial and industrial customers in earlier-stage markets. BTM storage is used to help lower customer utility bills, either by maximizing consumption from on-site generation sources, shifting demand to lower-priced periods, or reducing demand charges. Decision makers are often interested in enabling customers to lower energy bills as a matter of power system policy. The potential for a customer to lower their bills with energy storage depends on: (1) how the customer is allowed to operate the storage system; (2) the retail electricity tariff customers pay for consumption from the grid; and (3) how a customer is rewarded for energy exported back to the grid. Operations of BTM storage systems are subject to rules and regulations implemented and enforced through technical interconnection processes (see Technical Interconnection Process). Tariffs for grid electricity and energy exported back to the grid are defined under compensation schemes (see DER Compensation Schemes). Decisions around how to compensate BTM storage and other DER will not only impact adopting customers, but also nonadopting customers (e.g., cost-shifting), and decision makers must carefully consider how to balance the sometimes-competing interests of these customers.[15] Well-designed compensation mechanisms can help ensure that adopting customers neither negatively impact the utility nor nonadopting customers.

7.2.2 Customer Reliability and Resilience

Many customers are interested in energy storage as a means to ensure consistent and reliable access to energy, even when the power grid is down due to extreme events such as major storms. These customers include residents in areas with poor grid reliability, critical infrastructure facilities such as hospitals, or commercial and industrial consumers sensitive to power interruptions. These consumers may currently rely on uninterruptible power supply systems and diesel generators to meet their reliability and resilience needs, and it may be a policy objective to supplement or replace these systems with BTM energy storage (e.g., as part of decarbonization efforts).

7.2.3 Customer Power Quality

Some commercial and industrial customers may rely on high-quality electricity service to function and can be sensitive to even minor changes to grid voltage or frequency. Other consumers, such as manufacturing plants and industrial facilities, may be large enough to impact local power quality conditions on the distribution grid and be subject to penalties for causing local grid issues. Energy storage is one option for these consumers to ensure power quality for their own purposes as well as minimizing the risk of penalties associated with causing local grid issues.

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[15] For an overview of methods to determine how DERs can impact nonadopting customers through tariff increases, see *Distributed Solar Utility Tariff and Revenue Impact Analysis: A Guidebook for Internal Practitioners*. While this guidebook focuses on distributed solar, it can be straightforwardly extended to consider the impact of BTM storage or solar-plus-storage.

7.3 Building Blocks to Enable BTM Storage

The section discusses the policy and regulatory building blocks that can enable BTM storage deployment, organized by the three sequential undertakings that decision makers can consider as outlined in Section 7.1: enable interconnection; enable implicit service provision; enable active service provision.

7.3.1 Building Blocks to Enable Interconnection

Transparent Technical Interconnection Process: Creating a clear and transparent interconnection process not only makes it easier to integrate DERs, including BTM storage, to the electric distribution grid, but it can also help maintain the safety and reliability of the power system and help ensure defined standards are met. It involves specifying the different steps that installers and utilities must take in developing, reviewing, and approving (or rejecting) applications to connect to the grid and operate. A typical DER interconnection process includes the submission of an interconnection application following relevant procedures and requirements by a developer or customer, followed by a utility review of the application using technical screening criteria designed to identify grid impacts of the connecting system, which are used as a basis for application approval/rejections. Depending on various technical characteristics of the applying DER—namely the exporting versus non-exporting nature of systems—more or less stringent screening criteria may be applied (Zinaman, Bowen, and Aznar 2020; Horowitz et al. 2019). In many cases, faster and less rigorous interconnection processes and technical screens for nonexporting storage systems may be appropriate. In any case, defining rules that govern both the administrative and technical requirements for enabling the connection of DERs to the grid can provide valuable information to utilities and policymakers to support planning, while enabling DERs to connect safely and in a predictable manner. Conversely, poorly designed processes can lead to increased uncertainty for installers, dissatisfied customers, safety issues for customers and utility line workers, unnecessary administrative burdens for utilities, and/or negative impacts to clean energy goals.

Clearly Defined Grid Interconnection Codes: Grid interconnection codes are a set of requirements and procedures that define how systems can be connected to the electricity grid, and how the devices must operate to ensure safety and reliability. These local rules are often based on model international interconnection standards. Two critical sets of interconnection standards for DERs broadly include IEEE 1547-2018, which ensures regular, reliable responses from all DER interconnecting to the power system during both normal and abnormal grid conditions, and UL 1741 SA, which ensures that a particular inverter that interfaces between a DER and the power system is in compliance with IEEE 1547-2018. In addition to these standards, the unique characteristics of storage, acting both as a load and generation source at different times, may require additional considerations beyond existing procedures for DERs (Horowitz et al 2019). As BTM storage deployment grows, promulgating clearly defined grid interconnection codes for standalone storage and storage paired with distributed generation can help to ensure that BTM storage systems operate safely and reliably and also handles the complexity of these decisions for the customer. Addressing BTM storage in the existing grid interconnection codes is an incremental effort that can help standardize the performance of energy storage devices, support grid reliability and ensure safety (Zinaman et al. 2020).

Streamlined Local Siting and Permitting: Adhering to electrical, building, and fire safety codes and standards ensures the safe and reliable operation of BTM storage and can be part of the local or jurisdictional permitting authorities' screening procedures. Providing guidance to building owners and developers about the approval process, permitting fees, siting, signage, equipment, and other certification requirements can help lower costs and reduce the timeline for interconnection (Zinaman et al. 2020). Several model codes, equipment, and safety standards exist (e.g., UL 1973, UL 1741, UL 9540, UL 9540A, NFPA 111, NFPA 855) and help ensure installed systems will perform as expected under varying environmental conditions. Building and fire codes help minimize potential safety risks and fire hazards, and specific guidance based on size and location of BTM storage is needed for safe construction, installation, operation, and decommissioning (Gokhale-Welch and Stout 2021). Fire safety is a particular concern for lithium-ion battery storage systems, which can be vulnerable to thermal runaway and have become increasingly popular for customer-sited applications. Standardized, streamlined permitting processes for the installation of stand-alone BTM storage or distributed PV coupled with BTM storage is critical, especially as battery prices continue to fall and more devices are installed.

7.3.2 Building Blocks to Enable Implicit Service Provision

DER Compensation Mechanisms to Support Grid-Friendly Behavior: DER compensation mechanisms are a key policy and regulatory tool that can help facilitate the deployment of grid-friendly BTM storage and enable implicit service provision. Well-designed compensation mechanisms are market and context-specific, can drive customer behavior to shift load or adjust the timing of their exports to provide grid services, and can help support the objectives of various stakeholders, including regulators, utilities, system owners, and other ratepayers. Compensation mechanisms can be broadly divided into three components and collectively present a powerful tool to align customer incentives with power system needs.[16]

Metering and Billing Arrangements: Metering and billing arrangements outline how consumption and on-site generation are measured and compensated. Net energy metering (often referred to as net metering) allows a customer to export generation in excess of on-site demand to the grid for a credit to offset consumption in the current or future billing cycles. Similar to net energy metering, net billing allows customers to export electricity in excess of on-site consumption to the grid. However, banking of kWh credits does not occur. Rather, all grid exports are credited at a predetermined sell rate. Under both arrangements, the customer pays for any consumption from the grid at the rate specified within the applicable retail tariff.

Net energy metering does not incentivize the deployment of BTM storage with distributed generation, as it effectively treats the grid as a form of financial storage, allowing customers to “bank” generation in one hour for use in another hour. In comparison, a net billing policy typically features a sell rate lower than the volumetric retail energy rate, and thus incentivizes customers to self-consume on-site generation. As customer demand is often noncoincident with distributed PV production, a net billing scheme can incentivize the installation of BTM storage to maximize on-site consumption of distributed generation.

Cost-Reflective Retail Tariffs: Retail tariffs are the set of charges that retail customers are subject to for purchasing electricity from their utility. Retail tariff structure plays an important role for BTM storage applications, as it creates opportunities for customers to reduce their bills by managing their load to create value to the power system. Two common elements for cost-reflective retail tariffs are demand charges and time-of-use rates. Demand charges, typically applied to commercial and industrial customers, constitute a per-kW charge to peak demand for electricity during a given billing period. BTM storage can be used for peak shaving activities to reduce customer bills. Similarly, a time-of-use rate (or other time variate rates[17]) presents an opportunity to engage in load shifting (i.e., adjusting grid consumption from high-priced periods to low-priced periods using the storage device) and/or energy arbitrage (i.e., buying electricity at a lower price and selling it back to the grid at a higher price). Retail tariff design is an important consideration for BTM storage-plus-distributed PV systems for the same reasons, as it represents a cost-avoidance opportunity for the system owner if they self-consume on-site generation.

Cost Reflective Sell Rates: Cost-reflective sell rates set the compensation that an exporting DER system owner receives for the electricity exported from their system to the grid. Sell rates can be static, staying

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[16] See *Grid-Connected Distribution Generation: Compensation Mechanism Basics* for more information.
[17] For additional examples of time-variant retail tariff elements, see Faruqui et al. (2014).

fixed over the length of the compensation agreement or more dynamic and granular, varying by time and location. Allowing prices to reflect costs that vary over time and location can have several potential benefits at the transmission and distribution level, ultimately resulting in lower customer bills and reduced operational costs for the power system. However, such value-based sell rates are typically time-variant and sometimes location-dependent in nature—they can be complex to calculate, difficult for customers to understand and meaningfully respond to, and sometimes can be difficult to implement from a metering, billing, and administration standpoint.

New Metering Infrastructure. Introducing complexity in the tariff structure may necessitate more advanced metering solutions to capture detailed information about electricity consumption and production by the customer. Smart meters can support implicit service provision approaches by accurately measuring consumption and generation in high granularity, which is a necessary prerequisite for implementing time-of-use rates or demand charges (Zinaman et al. 2020). Promoting the installation of additional enabling infrastructure, such as smart thermostats, may help alleviate some of the complexity for the customer from cost-reflective retail tariffs and sell rates by automating responses to changes in electricity prices.

7.3.3 Building Blocks to Enable Active Service Provision

Additional Metering and Communications Infrastructure. Additional communications technology infrastructure will be needed under active grid service provision approaches (e.g., as part of an aggregation scheme) to monitor the state-of-charge of BTM storage devices and also to send signals to systems to charge or discharge. Such infrastructure is also critical to ensure system operators and utilities can verify the response of these distributed systems in order to inform compensation. Several grid codes and interconnection standards—such as IEEE 1547-2018—explicitly outline communications capabilities and protocols required from interconnecting systems to ensure they are able to share sufficient information with sufficient speed to adequately monitor and control them (Narang et al. 2020).

Clarifying Roles for BTM Storage on the Grid. Providing system services with assets located on the distribution system and behind a customer's meter represents a shift in traditional power system operation. Additional clarification from regulators on the types of services these systems can provide, and under what circumstances, can help developers and utilities better plan for the deployment of BTM storage services. For instance, regulators may want to define where (e.g., location on specific nodes) and whether different distributed technologies (e.g., front-of-the-meter solar PV and BTM energy storage) can be aggregated together to provide the bulk power and distribution system with service. In the United States, FERC Order 2222 seeks to support the development of participation models that include DERs and BTM storage for the provision of services to competitive wholesale electricity markets.

Regulations to Enable Business Model Innovation. Many customers lack access to the affordable upfront capital necessary to invest in energy storage systems. Additionally, many customers who install energy storage may lack the technical expertise needed to fully utilize the capabilities of their storage system, which is often dispatched to provide services in a relatively small number of hours, or as a small share of the total system capacity. Utilities and developers, conversely, do not have direct access to a customer's premises but have access to capital and often have the sophistication and interest to dispatch BTM storage systems to provide additional grid services. Novel ownership models can thus help share the costs and benefits of BTM energy storage systems but may need regulatory approval or encouragement to mature. Two ownership models, Bring Your Own Device and Storage-as-a-Service, have been used in some jurisdictions as storage deployment grows. Under the Bring Your Own Device business model, the storage system is owned and paid for by the customer upfront, with developers or utilities offering regular payments to the customer in exchange for control of the storage system during specific hours or in exchange for control over a portion of the storage system's capacity. Under Storage-as-a-Service, the developer or utility pays the initial upfront costs for the BTM storage system, which the customer has access to during outages or select hours in exchange for a regular payment on their utility bill.

Coordination Between the Transmission System, Distribution System, and Developer. While BTM storage can provide services to both the transmission and distribution system, storage systems have a limited charge and can only be available for a limited time before needing to recharge. Without proper coordination, it is possible that service provision to one set of stakeholders may interfere with service provision to another set of stakeholders. For instance, a battery sited behind a customer's meter could accidentally exacerbate congestion on a local distribution feeder while being dispatched to provide energy to the transmission system. Actors at various levels of the power system can work together to ensure local power system conditions are considered when dispatching customer-sited resources. Furthermore, stakeholders can develop a hierarchy of system services such that, when a conflict arises, there is clear guidance on how the BTM storage system is supposed to operate to be of most benefit to the grid (e.g., ensuring that reliability services take precedence over market revenues). Better coordination also helps ensure that BTM resources are not double-compensated for services they provide to the power system.

8 Conclusion

The energy storage market is quickly evolving, and the opportunities for power system modernization, decarbonization, and economic development that this technology suite presents are both significant and multidimensional. Energy storage has piqued the interest of policymakers in many countries as they chart a path to meeting their Nationally Determined Contributions under the UNFCCC Paris Climate Agreement and update their NDCs in preparation for COP26. At the same time, major development finance institutions are making significant commitments to invest in energy storage in the developing world.[18] Between 2018 and 2040, energy storage installations are forecast to grow over 100 times (BloombergNEF 2019).

However, though certain storage technologies have reached commercial scale and deployment, many utilities, decision makers, and consumers are still in a familiarization phase with energy storage. As a result, the electricity industry has not yet converged on standard practices for identifying and evaluating investment decisions for energy storage systems, nor for facilitating participation of energy storage in power systems. Without modifications to planning, investment, and participation frameworks, energy storage may not grow organically in most jurisdictions. However, policy and regulatory frameworks can enable jurisdictions to develop locally appropriate energy storage projects and place energy storage on a more level playing field with conventional grid solutions. The prospective roles that energy storage might play within an individual power system will be diverse and may change over time as the power system evolves. Furthermore, as costs continue to decline and manufacturing capacity increases, there will be an increasing number of opportunities to deploy energy storage, from longer duration applications to hybrid systems, to provision of more cost-effective grid services. While not a panacea, storage can be expected to play an increasingly prominent role in easing the transition to decarbonized, flexible, reliable, resilient power systems.

While the landscape is quickly evolving, power sector policymakers, regulators, and electric utilities can nevertheless begin preparing now for decisions about where, when, how much, and what types of energy storage are appropriate to serve emerging power system needs. To get ahead of the curve, decision makers can start by focusing on the building blocks outlined in this report, including by making changes to traditional power system planning methods to better incorporate storage as a prospective grid solution and augmenting technical procedures to enable grid interconnection. There may also be opportunities for decision makers to increase their familiarity with energy storage technologies through pilot projects, especially in applications where replicability potential is high and there is a commitment to life cycle monitoring where learnings can be identified and systematically disseminated.

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[18] For instance, the World Bank's Energy Storage Partnership is aiming to foster significant international cooperation and development finance disbursement for energy storage technologies. For more information, see: https://esmap.org/sites/default/files/ESP/ESP-factsheet_Nov2020.pdf.

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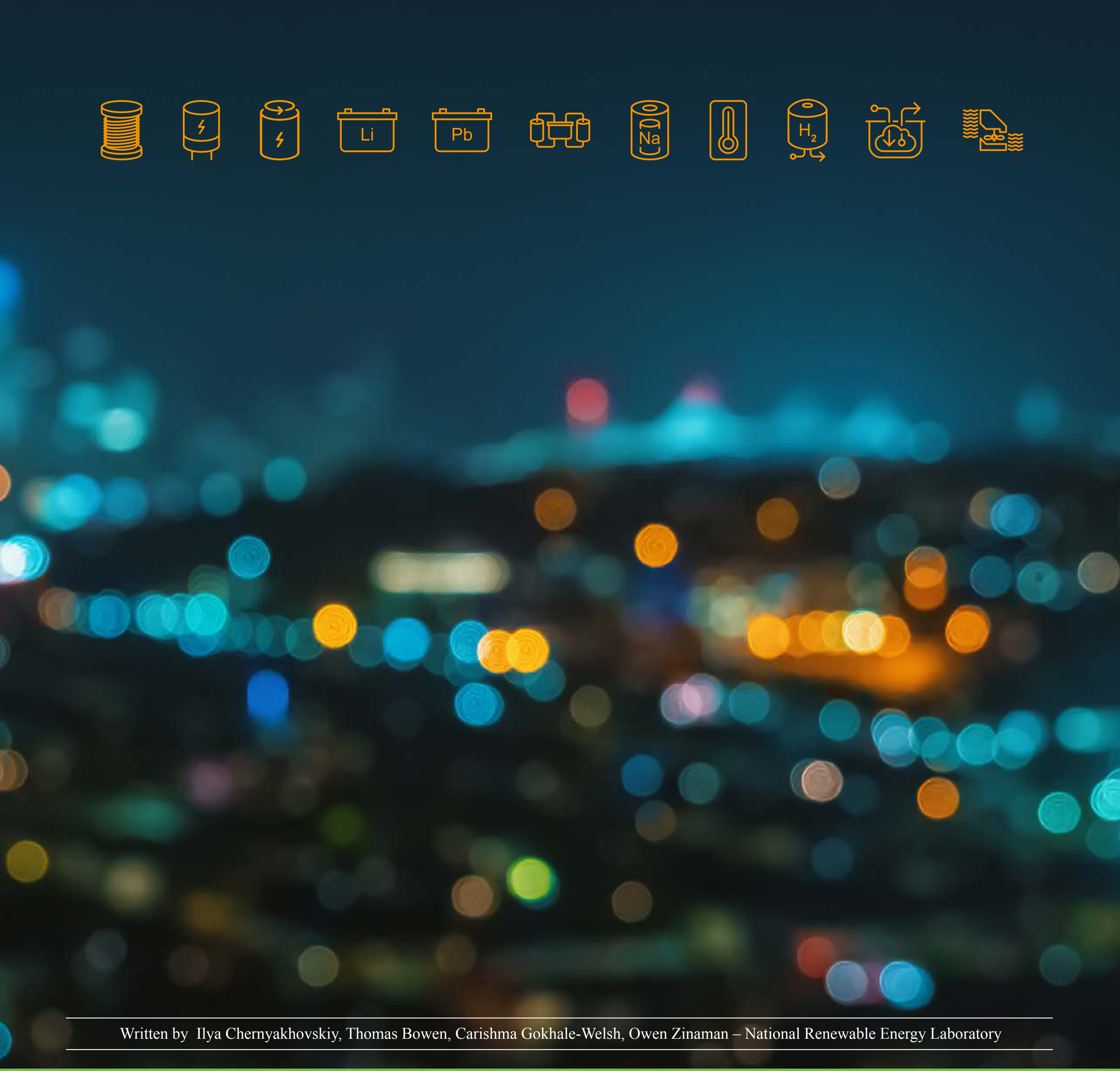

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