Electric Power Industry Needs for Grid-Scale Storage Applications

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ABOUT THIS REPORT

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EXECUTIVE SUMMARY

Reliable access to cost-effective electricity is the backbone of the U.S. economy, and electrical energy storage is an integral element in this system. Without significant investments in stationary electrical energy storage, the current electric grid infrastructure will increasingly struggle to provide reliable, affordable electricity, and will jeopardize the transformational changes envisioned for a modernized grid. Investment in energy storage is essential for keeping pace with the increasing demands for electricity arising from continued growth in U.S. productivity, shifts and continued expansion of national cultural imperatives (e.g., emergence of the distributed grid and electric vehicles), and the projected increase in renewable energy sources.

Stationary energy storage technologies will address the growing limitations of the electricity infrastructure and meet the increasing demand for renewable energy use. Widespread integration of energy storage devices offers many benefits, including the following:

- Alleviating momentary electricity interruptions
- Meeting peak demand
- Postponing or avoiding upgrades to grid infrastructure
- Facilitating the integration of high penetrations of renewable energy
- Providing other ancillary services that can improve the stability and resiliency of the electric grid

STRATEGIC PRIORITIES FOR WIDESPREAD DEPLOYMENT OF ENERGY STORAGE TECHNOLOGIES

The widespread deployment of reliable and economically viable energy storage technologies will require support from the U.S. Department of Energy (DOE) and collaboration among energy storage researchers and developers, the electric power industry, and other stakeholders. While some energy storage technologies are now ready for commercial demonstration, the current market structure does not recognize the benefits of energy storage. Other promising technology options require additional research and development to improve performance and reduce costs. A coordinated approach will address challenges of a deficient market structure, limited large-scale demonstrations, insufficient technical progress, lack of standards and models, and weak stakeholder understanding of existing and emerging energy storage technologies.

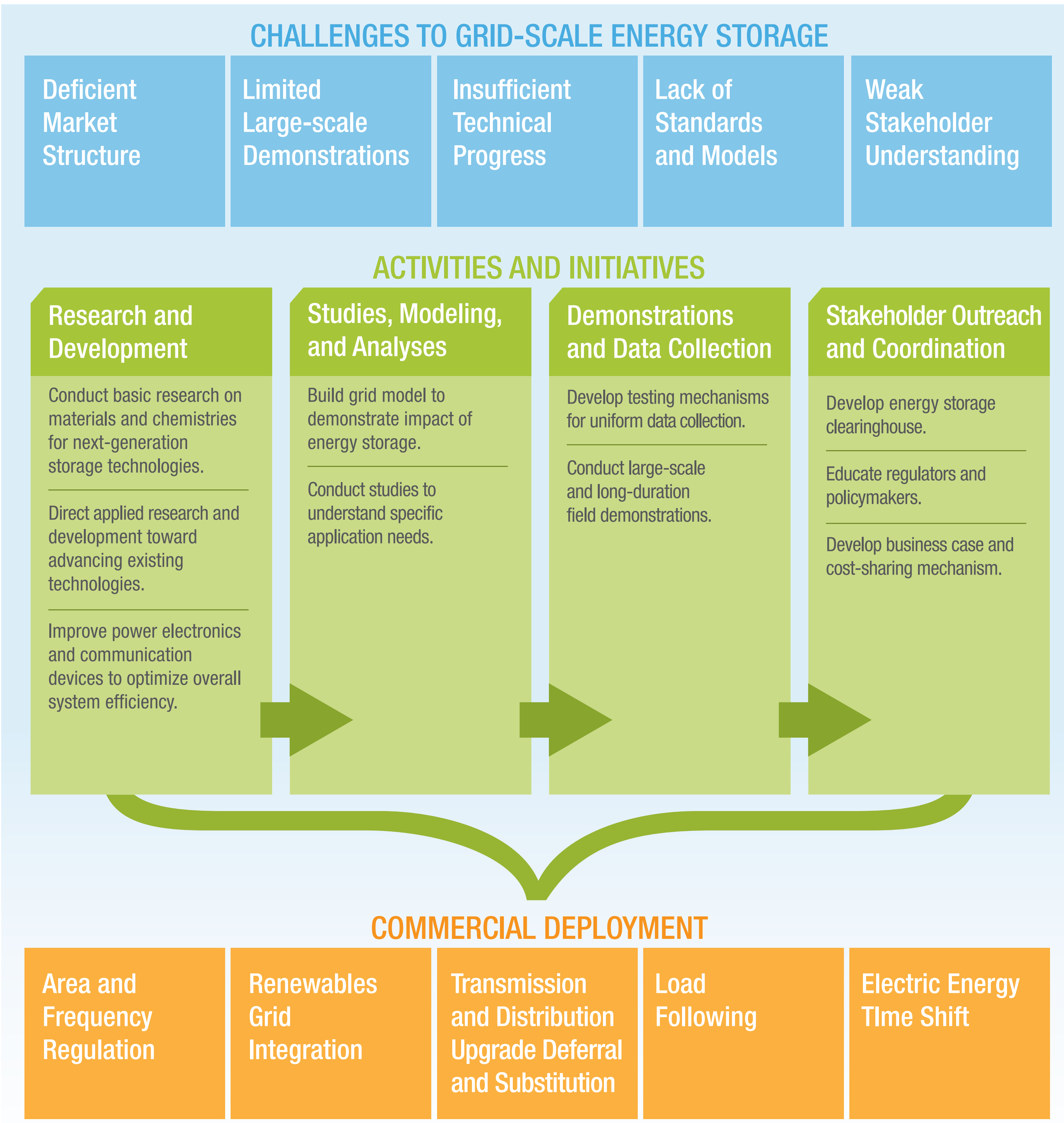
Figure 1 outlines the high-priority activities and initiatives that are necessary to overcome these challenges and advance the deployment of energy storage devices today through 2030, with particular emphasis on the 1- to 5-year and 5- to 10-year time frames. These activities encompass research and development; studies, modeling, and analyses; demonstrations and data collection; and stakeholder outreach and coordination. While these four activity areas logically propel individual storage technologies from their current status to commercialization, efforts focused on a portfolio of storage options must occur simultaneously to ensure the continued advancement and increased deployment of existing and next-generation energy storage technologies.

- **RESEARCH AND DEVELOPMENT –** Continuous basic and applied research on both new and existing energy storage technologies will provide the electric power industry with more reliable, efficient, and affordable energy storage devices.

- **STUDIES, MODELING, AND ANALYSES –** Studies, modeling, and analyses can be conducted to assess and simulate the impact and value that energy storage technologies will have at grid scale.
- **DEMONSTRATIONS AND DATA COLLECTION –** Large-scale field testing and demonstration of various technologies in multiple applications and regions across the country will validate the performance of energy storage technologies and demonstrate their value to regulators, utilities, and other potential owners.
- **STAKEHOLDER OUTREACH AND COORDINATION –** Outreach to energy storage stakeholders can promote collaboration on technology development, helping energy storage technologies to reach market penetration more quickly and to operate more efficiently and reliably once successfully integrated into the grid.

Committing to these activities will allow DOE, technology developers, and the electric power industry to pursue a coherent market entry strategy for energy storage technologies in grid-scale applications. In the near term, energy storage is most likely to be commercially deployed for the following applications: area and frequency regulation, renewables grid integration, transmission and distribution upgrade deferral and substitution, load following, and electric energy time shift. The use of stationary energy storage devices for these applications has the potential to transform the U.S. electric grid, offering significant benefits to the electric power industry and U.S. citizens who depend on cost-effective, reliable electricity.

FIGURE 1: UTILITY INDUSTRY NEEDS FOR GRID-SCALE STORAGE STRUCTURE AND CONTENT



WORKSHOP PARTICIPANTS CONVENE TO DISCUSS
THE RESULTS OF THE WORKSHOP BREAKOUT SESSIONS.

INTRODUCTION AND PROCESS

Stationary energy storage at the grid scale promises to transform the electric power industry. Energy storage technologies are a key enabler of grid modernization, addressing the electric grid's most pressing needs by improving its stability and resiliency. Investment in energy storage is essential for keeping pace with the increasing demands for electricity arising from continued growth in U.S. productivity, shifts and continued expansion of national cultural imperatives (e.g., the distributed grid and electric vehicles), and the projected increase in renewable energy sources. The development of cost-effective energy storage technologies will provide the flexibility that the electric grid needs to respond to fluctuating and escalating electricity demands, ensuring that electricity is available when and where it is needed.

Current research and demonstration efforts by the U.S. Department of Energy (DOE), the national laboratories, electric utilities and their trade organizations, storage technology providers, and academic institutions provide the foundation for the extensive effort that is needed to accelerate widespread commercial deployment of energy storage technologies. Many policymakers and other stakeholders are still unaware of the benefits these technologies can provide to a variety of grid applications. In order for grid-scale storage to become a reality, the electric power industry, researchers, policymakers, and other stakeholders need to understand and address the storage needs of the electric power industry, the challenges to the widespread commercial deployment of energy storage devices, and the opportunities these technologies have to modernize the electric grid.

The Minerals, Metals & Materials Society (TMS) organized a workshop to support DOE's contributions to the commercialization of stationary energy storage at grid scale. The DOE Office of Electricity Delivery and Energy Reliability, the DOE Office of Energy Efficiency and Renewable Energy Solar Technology Program, and Sandia National Laboratories sponsored this facilitated workshop that was designed to garner critical information from forward thinkers to develop a path forward for grid-scale energy storage.

Thirty-five stakeholders and experts from across the electric power industry, research, and government communities attended the workshop on June 19–20, 2010 in Albuquerque, New Mexico. The workshop focused its discussions on determining the performance targets that energy storage technologies must meet and the challenges these technologies must overcome to achieve widespread commercialization in grid-scale applications. Participants applied diverse perspectives to identify methods for technology commercialization and implementation, the needs of the electric power industry from a technology-driven perspective, and the needs of the power companies and electric system planners and operators who will use energy storage technologies.

While all energy storage technologies and systems were within the scope of the workshop, the main focus was on technologies for which DOE involvement could accelerate progress toward commercial deployment at grid scale. The time frame under consideration was today through 2030, with particular emphasis on the 1- to 5-year and 5- to 10-year time frames.

Based on the consensus of the workshop participants, this report provides the following guidance to DOE:

- Opportunities and priority applications for grid-scale storage
- Challenges to widespread commercial deployment of storage technologies
- Activities and initiatives for widespread storage adoption

An additional workshop, which immediately followed the workshop on the energy storage needs of the electric power industry, convened experts to identify advanced materials and energy storage devices that can address the needs of the electric power industry. The reports from these workshops will inform future DOE program planning and ultimately help to commercialize energy storage at grid scale.

U.S. ELECTRICITY GENERATION, TRANSMISSION, AND DISTRIBUTION INFRASTRUCTURE REQUIRES UPGRADES TO KEEP PACE WITH INCREASING U.S. ELECTRICITY DEMANDS.

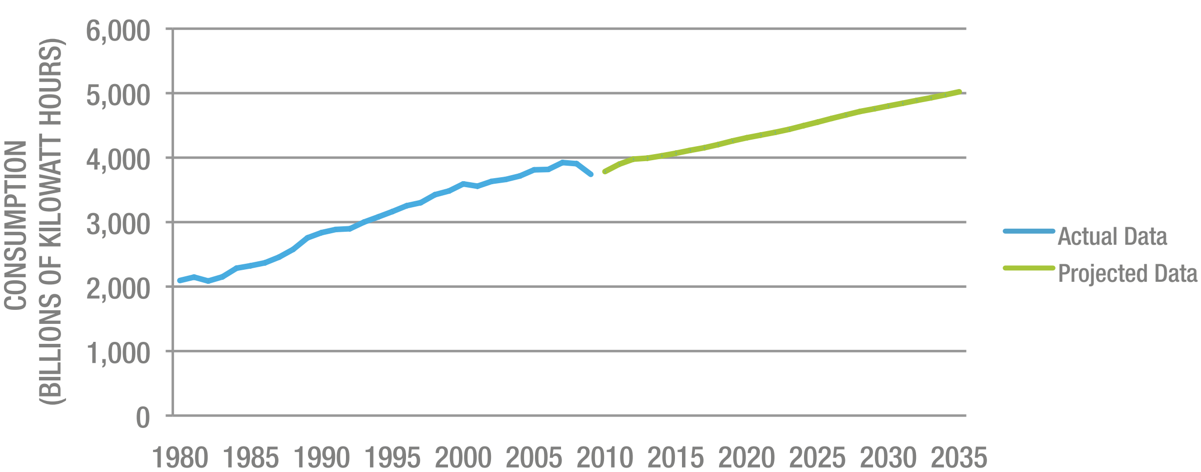
THE STATE OF THE ELECTRIC GRID: THE CASE FOR STORAGE

Electricity demand in the United States is steadily rising; in 2009, electricity consumption was more than five times what it was 50 years ago.[1] The aging electric grid does not have the ability to transmit these large amounts of electricity from the point of generation to the end user as reliably as the U.S. economy requires.[2] As wind, solar, and other variable renewable energy sources are deployed in greater quantities, transmission and distribution lines are also unable to accommodate the variable power production that often comes from remote locations. Increasing electricity demands and the shift to renewable energy sources in the United States will require immediate and cost-effective grid updates to provide consumers with electricity at the cost and with the reliability they have come to expect.

ELECTRICITY CONSUMPTION IN THE UNITED STATES

U.S. electricity consumption is projected to continue growing in the years ahead (see Figure 2). U.S. electricity demand is expected to increase at a rate of 1% each year through 2035, at which point the country is expected to consume 5,021 billion kilowatt-hours of electricity.[3] This increasing demand has and will continue to put stress on electricity generation, transmission, and distribution infrastructure. To meet the increased electricity demands expected by 2035, an additional 250 gigawatts of generating capacity will have to be added to the electricity generation infrastructure. Much of this additional generating capacity will be derived from renewable energy sources like wind and solar power.[4]

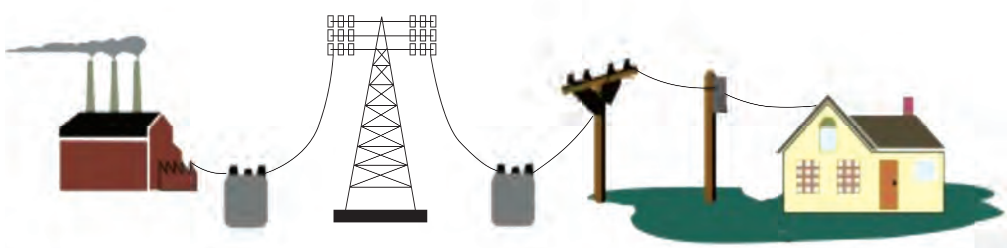
FIGURE 2: U.S. NET ELECTRICITY CONSUMPTION[5]



LIMITATIONS OF THE CURRENT ELECTRIC GRID

The U.S. electric power grid is a complex system that transfers electricity generated at power plants to substations via 160,000 miles of transmission lines, and then to a variety of consumers throughout the nation via distribution lines (see Figure 3). This system was developed by connecting local grids to form more robust, larger networks that would ensure that nearly all Americans had dependable access to electricity.[6] While this methodology worked in the past, widespread development has overburdened the grid in high-demand regions.

FIGURE 3: ELECTRICITY TRANSMISSION FROM GENERATION TO POINT OF USE [7]



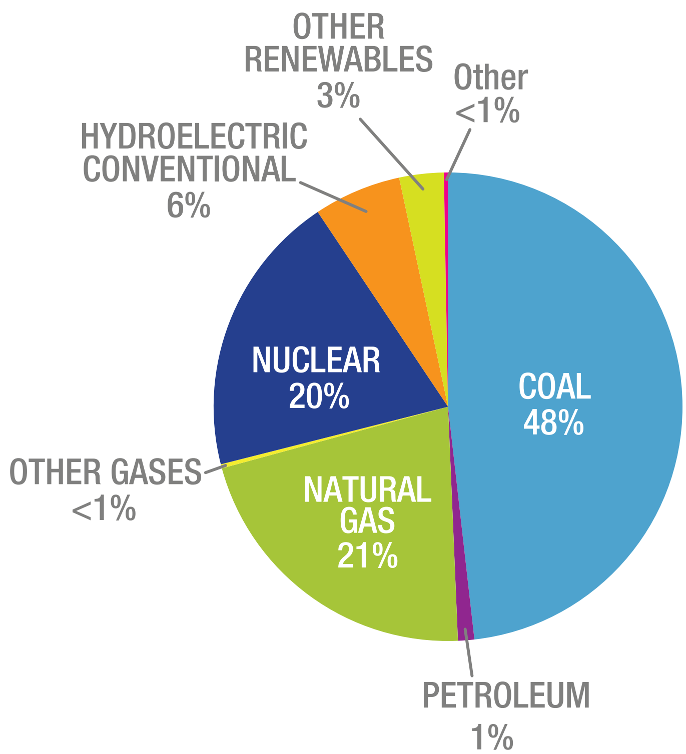
As a result of this increase in demand, the grid often experiences interruptions in electric service. The cost of power interruptions to U.S. electricity consumers is approximately $80 billion each year—about one-third of annual electricity costs.[8] Many of these interruptions occur due to problems at the distribution level and may be mitigated by distributed energy storage approaches.

Service interruptions exhibit the inefficiencies of current grid networks and emphasize the dire need to modernize the electric grid so it can respond to increasing electricity demands and shifts in generation sources. While building new generation plants and transmission and distribution lines is a costly and time-consuming endeavor, energy storage can optimize the capacity factor of current grid operation. Advanced storage could provide a reliable and cost-effective alternative to infrastructure expansion.

THE SHIFT TO RENEWABLE ENERGY SOURCES

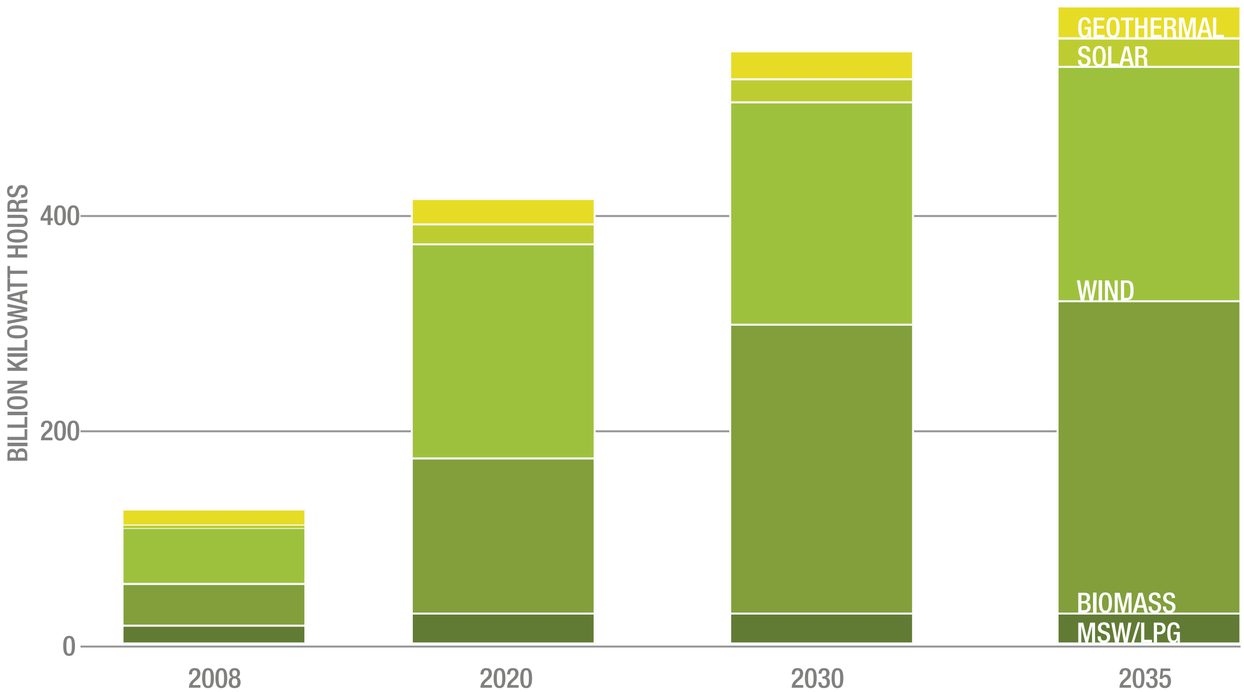
Perhaps the most significant trend driving the need for grid-scale energy storage is the shift to renewable energy sources, such as wind and solar. While coal has traditionally been the largest fuel source for U.S. electricity generation, emphasis on cleaner energy and decreased reliance on fossil fuels and other nonrenewable sources has placed greater attention on renewable sources for electricity generation. Figure 4 displays the breakdown of electrical power generation by source for 2008.

FIGURE 4: U.S. ELECTRIC POWER INDUSTRY NET GENERATION BY FUEL, 2008[9]



Currently, renewable sources (including hydroelectric) provide only 9% of the U.S. electricity supply, but federal and state incentive programs and regulations are driving the adoption of renewable energy systems and the purchase of electricity generated from renewable sources (see Figure 5 for projected electricity generation from renewables through 2035). Forty-two states and the District of Columbia have already set specific mandates or goals for a certain percentage of electric power generation and sales to come from renewable energy sources. And utilities across 47 states now offer their consumers the opportunity to purchase electricity generated by renewable energy resources.[10]

FIGURE 5: NONHYDROELECTRIC RENEWABLE ELECTRICITY GENERATION, 2008–2035[11]



MSW/LPG IS MUNICIPAL SOLID WASTE/LIQUEFIED PETROLEUM GAS

While beneficial from an environmental standpoint, the increased demand for renewables-generated power will place increased stress on the electric grid. The variable nature of renewable sources, particularly wind and solar, poses reliability concerns that must be addressed as renewable sources serve a larger role in electricity generation.[12] The often remote locations of these sources also causes issues with renewables grid integration and the capacity of transmission and distribution infrastructure.[13] Energy storage technologies are well positioned to help offset the intermittent electricity generation from renewable sources and could serve an integral role in the increased adoption of these alternative energy sources.

ENERGY STORAGE OFFERS SOLUTIONS

As previously emphasized, one of the most promising approaches to addressing the growing limitations of the electric grid and the increasing demand for renewable energy is to incorporate stationary energy storage technologies into the U.S. electric grid. With a variety of short-, mid-, and long-term storage options serving multiple applications, energy storage devices can provide multiple simultaneous benefits, including balancing services such as regulation and load following; supply power during brief disturbances to reduce outages and the financial losses that accompany them; defer and substitute transmission and distribution upgrades; and greatly enhance the future resilience of the electric grid while preserving its reliability.

APPLICATIONS

Stationary energy storage technologies can be applied to a variety of applications that help the electric power industry provide customers with reliable and affordable electricity. By responding to the grid faster than traditional generation sources, operating efficiently at partial load, and being able to vary discharge times depending on application need, energy storage devices can help alleviate momentary interruptions and meet peak demand without requiring major upgrades to grid infrastructure. Some storage applications (e.g., electric supply capacity, area regulation, and reserve capacity) enable compensation from some of the existing ancillary services markets in certain regional transmission organizations. The purpose and benefits of energy storage applications are briefly discussed in the following table.

TABLE 1: GRID STORAGE APPLICATIONS[14]

ELECTRIC (GRID-SUPPLIED) ENERGY TIME SHIFT	Charges the storage plant with inexpensive electric energy purchased during low price periods and discharges the electricity back to the grid during periods of high price
ELECTRIC SUPPLY CAPACITY	Reduces or diminishes the need to install new generation capacity
LOAD FOLLOWING	Alters power output in response to variations between electricity supply and demand in a given area
AREA REGULATION	Reconciles momentary differences between supply and demand within a given control area
ELECTRIC SUPPLY RESERVE CAPACITY	Maintains operation when a portion of normal supply becomes unavailable
VOLTAGE SUPPORT	Counteracts reactive effects to grid voltage so that it can be upheld or reinstated
TRANSMISSION SUPPORT	Enhances transmission and distribution system performance by offsetting electrical irregularities and interruptions
TRANSMISSION CONGESTION RELIEF	Avoids congestion-related costs by discharging during peak demand to reduce transmission capacity requirements
TRANSMISSION AND DISTRIBUTION UPGRADE DEFERRAL AND SUBSTITUTION	Postpones or avoids the need to upgrade transmission and/or distribution infrastructure
SUBSTATION ON-SITE POWER	Provides power to switching components and communication and control equipment
TIME-OF-USE ENERGY COST MANAGEMENT	Reduces overall electricity costs for end users by allowing customers to charge storage devices during low price periods
DEMAND CHARGE MANAGEMENT	Reduces charges for energy drawn during specific peak demand times by discharging stored energy at these times
ELECTRIC SERVICE RELIABILITY	Provides energy during extended complete power outages
ELECTRIC SERVICE POWER QUALITY	Protects on-site loads against poor quality events by using energy storage to protect against frequency variations, lower power factors, harmonics, and other interruptions
RENEWABLES ENERGY TIME-SHIFT	Stores renewable energy (which is frequently produced during periods of low demand) to be released during periods of peak demand
RENEWABLES CAPACITY FIRMING	Addresses issues with ramping from renewable sources by using stored energy in conjunction with renewable sources to provide a constant energy supply
WIND/SOLAR GENERATION GRID INTEGRATION	Assists in wind- and solar-generation integration by reducing output volatility and variability, improving power quality, reducing congestion problems, providing backup for unexpected generation shortfalls, and reducing minimum load violations

TECHNOLOGIES

Storage technologies currently being researched, developed, and deployed for grid applications include high-speed flywheels, electrochemical capacitors, traditional and advanced lead-acid batteries, high-temperature sodium batteries (e.g., sodium-sulfur and sodium-nickel-chloride), lithium-ion batteries, flow batteries (e.g., vanadium redox and zinc bromine), compressed air energy storage, pumped hydro, and other advanced battery chemistries such as metal-air, nitrogen-air, sodium-bromine, and sodium-ion. While pumped hydro has achieved widespread deployment, all of the suitable pumped hydro locations are currently being used and only meet a small portion of the baseload electricity needs. The wide range of chemistries and structures of these devices enables them to be tailored to meet the discharge duration, capacity, and frequency demands of specific applications.

Storage applications and their associated storage technologies can be loosely divided into power applications and energy management applications, which are differentiated based on storage discharge duration. Technologies used for power applications are usually used for short discharge durations, ranging from fractions of a second to approximately one hour, to address faults and operational issues that cause disturbances such as voltage sags and swells, impulses,

FIGURE 6: OVERVIEW OF STORAGE TECHNOLOGIES[15]

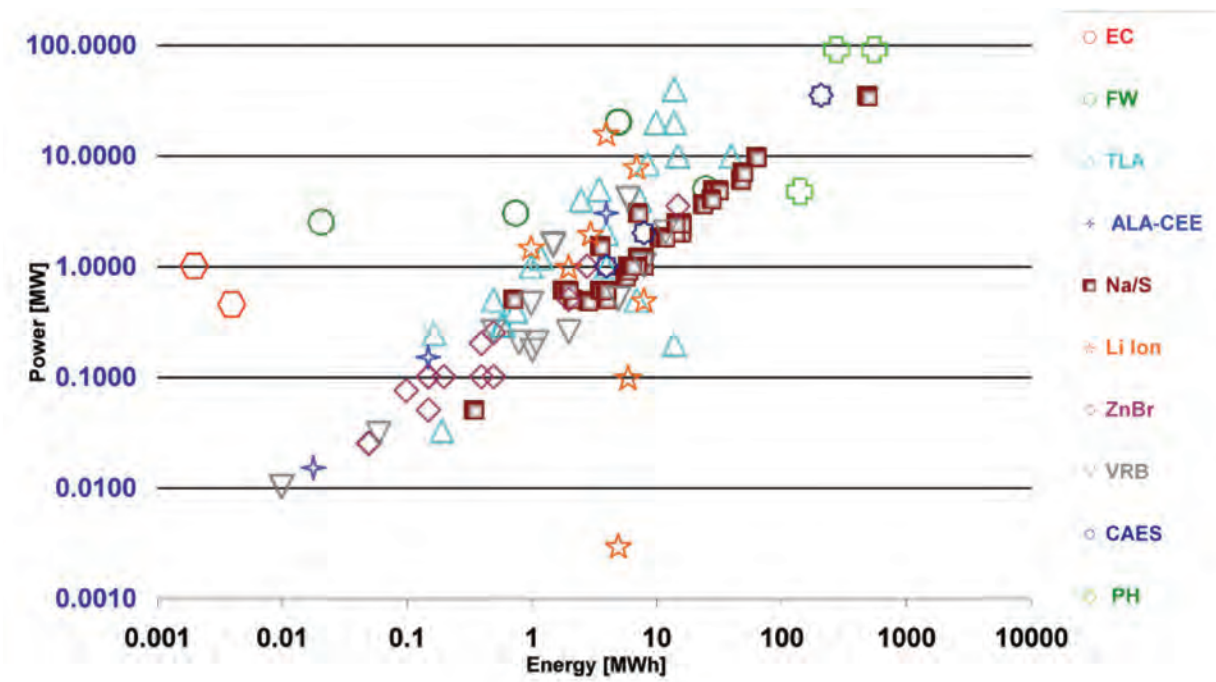
STORAGE TECHNOLOGY	MAIN ADVANTAGE (RELATIVE)	DISADVANTAGE (RELATIVE)	POWER APPLICATION	ENERGY APPLICATION
HIGH-SPEED FLYWHEELS	High Power	Low Energy Density	●	⚪
ELECTROCHEMICAL CAPACITORS (EC)	Long Cycle Life	Very Low Energy Density	●	⚪
TRADITIONAL LEAD ACID (TLA)	Low Capital Cost	Limited Cycle Life	●	◯
ADVANCED LA WITH CARBON ENHANCED ELECTRODES (ALA-CEE)	Low Capital Cost	Low Energy Density	●	●
SODIUM SULFUR (NaS)	High Power and Energy Density	Cost and Requirement to Run at High Temperatures	●	●
LITHIUM-ION (LI-ION)	High Power and Energy Density	Cost and Increased Control Circuit Needs	●	◗
ZINC-BROMINE (ZnBr)	Independent Power and Energy	Medium Energy Density	◗	●
VANADIUM REDOX (VRB)	Independent Power and Energy	Medium Energy Density	◗	●
COMPRESSED AIR ENERGY STORAGE (CAES)	High Energy, Low Cost	Special Site Requirements	⚪	●
PUMPED HYDRO (PH)	High Energy, Low Cost	Special Site Requirements	⚪	●

● FULLY CAPABLE AND REASONABLE
◗ REASONABLE FOR THIS APPLICATION
◯ FEASIBLE BUT NOT QUITE PRACTICAL OR ECONOMICAL
⚪ NOT FEASIBLE OR ECONOMICAL

and flickers. Technologies used for energy management applications store excess electricity during periods of low demand for use during periods of high demand. These devices are typically used for longer discharge durations exceeding one hour to serve functions that include reducing peak load and integrating renewables. Figure 6 indicates which storage technologies are better suited for power and which are better suited for energy applications. With further research, development, and demonstration, these technologies are more likely to achieve widespread commercial deployment on the U.S. electric grid.

The storage technologies in Figure 6 are currently being demonstrated and deployed across the United States, with many other installations planned for the next five years. The energy and power capacities of some of the current and planned worldwide installations are provided in Figure 7.

FIGURE 7: INSTALLED AND PLANNED ENERGY STORAGE SYSTEMS, APRIL 2010[16]



Increasing the amount of deployed storage technologies is critical to the widespread deployment of energy storage systems. Deploying storage technologies in real-world settings provides investors, policymakers, and researchers with the data they need to continue innovating while encouraging the utility buy-in needed to make energy storage work at grid scale. To date, developments in stationary storage technologies have already advanced these technologies to be more cost-effective and secure than current methods for integrating renewables and enhancing grid reliability. With factors such as increasing electricity demand, aging infrastructure, and the shift to renewable energy sources driving the need for a modernized grid now, a strategic approach to the deployment of grid-scale energy storage technologies has the potential to provide a cost-effective, near-term solution.

4 X 1-MEGAWATT, 15-MINUTE LITHIUM ION SYSTEM IN PJM INTERCONNECTION

OPPORTUNITIES AND PRIORITY APPLICATIONS FOR GRID-SCALE STORAGE

With the increasing penetration of variable renewable energy sources, electricity generation is no longer constant, yet must continue to meet fluctuating electricity demands. This imbalance, along with the current grid limitations and aging infrastructure, has the potential to challenge grid operators as they manage an increasingly dynamic electric grid. Stationary energy storage technologies and devices can be used to serve multiple functions that can increase the reliability and resilience of the electric grid. These technologies can stabilize voltage and frequency, relieve momentary and prolonged stress on the grid, offset the need to build new power plants to meet increasing electricity demand and support increasing variable renewables generation, and store energy for discharge during times of high price or peak demand.

METRICS FOR STORAGE TECHNOLOGIES AND APPLICATIONS

To provide the maximum benefit to the electric power industry and electricity end users, storage technologies must meet certain economic, technical performance, and design targets for energy storage applications. While each energy storage application will require different specifications, these interrelated factors must also be considered to ensure the widespread deployment of grid-scale energy storage.

SYSTEM ECONOMICS is the most important metric to the electric power industry. Consumers are accustomed to having electricity when they need it and at affordable prices, which makes the lifecycle cost of storage technologies critical to their widespread adoption. Some stakeholders in the electric power industry believe that an energy storage technology must be competitive with the cost of currently available technologies used for peak electricity generation (e.g., gas turbines) and provide increased efficiency and other benefits that adequately offset capital, operating, and lifetime costs. While this view fails to recognize the full benefits of energy storage, some decision makers in the electric power industry continue to view storage as a peak generation substitute and value it accordingly. In order to achieve widespread implementation at grid scale, the cost of stationary storage devices overall must continue to decline.

The **TECHNICAL PERFORMANCE** of an energy storage device has a significant impact on overall system economics. In addition to being an affordable option, technologies must be able to meet the performance needs of a particular application. These performance needs are application-specific, but include the device's cycle life, response time, rate of charge and discharge, and efficiency. If a system does not meet the needs of its intended application, it is unlikely to be adopted. Advanced technologies must not only lower costs but exceed technical performance requirements when compared to currently available technologies.

SYSTEM DESIGN, which includes the storage device (e.g., battery, flywheel, regenerative fuel cell, or capacitor), the power conditioning and control systems that allow the system to communicate with the electric grid, and any other ancillary equipment necessary for the device's operation (e.g., auxiliary cooling systems), is also interrelated with the cost and technical performance of an energy storage system. The scalability of a system will depend on many factors, including materials availability, the feasibility of automated manufacturing, the availability of production mechanisms, and system complexity. In addition, the system design must meet the safety standards of the electric power industry, managing any health and safety risks to utility workers and the surrounding community.

Storage technologies that meet the economic, technical performance, and system design requirements of the intended application are well positioned to achieve widespread adoption in the electric power industry.

METRICS AND TARGETS FOR PRIORITY STORAGE APPLICATIONS

There are five storage applications that have the greatest overall potential to benefit power system planning and operations: area and frequency regulation, renewables grid integration, transmission and distribution upgrade deferral and substitution, load following, and electric energy time shift. Area and frequency regulation and certain aspects of renewables grid integration are short-duration power management applications, while transmission and distribution upgrade deferral and substitution, load following, and electric energy time shift (including renewables) are long-duration energy management applications.

The stationary energy storage technologies applied to these applications must meet certain economic, technical performance, and design targets in order to optimize grid functionality. While the metrics and targets will vary depending on the specific energy storage technology or device and the location of the application, they can serve as guidelines for researchers and the electric power industry to assess the value of individual technologies. Many storage technologies currently meet one or several of the proposed metrics. However, in order to achieve widespread commercial deployment, storage systems must meet the set of targets to offer the right combination of performance and cost-effectiveness required for market acceptance. The metrics and targets for storage technologies applied to area and frequency regulation, renewables grid integration, transmission and distribution upgrade deferral and substitution, load following, and electric energy time shift are provided in the following section.

AREA AND FREQUENCY REGULATION (SHORT DURATION)

Energy storage technologies are well suited to resolve momentary differences between supply and demand, as well as fluctuations in grid frequency. The current area and frequency regulation method uses turbines to balance constantly shifting load fluctuations by varying frequency and periodically adjusting generation in response to a signal from the system operator. Spinning reserves are used by electrical plants to quickly ramp up to full output when another generator goes offline; however, these generators must run constantly to assure power quality, which causes significant pollution.

The use of an energy storage technology has the potential to be far faster than regulation by a gas or steam turbine. This faster response time can minimize momentary electricity interruptions, which are more costly than sustained interruptions.[17] These storage technologies can vary output rapidly, changing from no output to full output within seconds. To optimize efficiency and response time, energy storage technologies used for area and frequency regulation must be able to communicate with the grid quickly and efficiently. Using storage for area and frequency regulation can significantly reduce the costly consequences of power interruptions at high-tech industrial and commercial facilities.

The performance targets of energy storage technologies used for area and frequency regulation emphasize the importance of system cost, system lifetime, discharge duration, response time, and roundtrip efficiency metrics. If a storage technology is able to meet these targets for area and frequency regulation, the technology is well positioned to be adopted by the electric power industry to assist with the recovery from momentary disturbances.

AREA AND FREQUENCY REGULATION (SHORT DURATION)		
Reconciles momentary differences between supply and demand within a given area		
Maintains grid frequency		
METRIC	**TARGET**	**SUPPORTING INFORMATION**
SERVICE COST	$20 per MW per hour	The current throughput cost of area and frequency regulation services is $50 per MW per hour.
SYSTEM LIFETIME	10 years	System lifetime is based on 4,500 to 7,000 cycles per year.
DISCHARGE DURATION	15 minutes to 2 hours	Storage technologies should have symmetric charge and discharge rates for this application.
RESPONSE TIME	<1 second	Since this application is intended to reconcile momentary differences, the storage technology must be able to respond to grid signals as fast as technologically possible.
ROUNDTRIP EFFICIENCY	75%–90%	Roundtrip efficiency is the efficiency measured at the transformer of the energy output divided by the energy input.

RENEWABLES GRID INTEGRATION (SHORT DURATION)

The increasing integration of renewable energy into U.S. energy supply can reduce reliance on fossil fuels and emissions from electricity generation. However, the intermittent nature of alternative energy sources introduces generation variability that can cause operational and integration issues when connected to the electric grid on a commercial scale. These issues fall into two general areas: short-duration (e.g., ramp-up/ramp-down) and long-duration (e.g., electricity energy time shift to better match renewable production with demand). This section addresses the short-duration issues; the long-duration issues are addressed later in this document.

Energy storage technologies can support the increased penetration of renewables-generated electricity by smoothing the power from these sources, thereby easing grid operation where large amounts of wind and solar generation have been deployed. To optimize the effectiveness of these operations, storage technologies need the ability to communicate and respond to the grid through the system operator.

Performance targets for storage technologies used for renewables grid integration address roundtrip efficiency, system lifetime, capacity, and response time metrics. If a storage technology is able to meet these targets for the area and frequency regulation application, the technology is more likely to be adopted by the electric power industry.

RENEWABLES GRID INTEGRATION (SHORT DURATION)		
Offsets fluctuations of short-duration variation of renewables generation output		
METRIC	**TARGET**	**SUPPORTING INFORMATION**
ROUNDTRIP EFFICIENCY	75%–90%	Roundtrip efficiency is the efficiency of the energy input measured at the transformer divided by the energy output.
SYSTEM LIFETIME	10 years	System lifetime will vary by technology and the number of cycles per year, but 10 years with high cycling would be a sufficient technology lifetime. Low-cost, shorter-lived storage technologies that can be recycled cost-effectively may offer another pathway to achieving system cost-effectiveness.
CAPACITY	1 MW–20 MW	The capacity need of a storage technology will depend on the size and intermittency of the renewables operation (e.g., a large wind farm with periods of strong wind and no wind has high potential to contribute to the grid but will be more effective with storage).
RESPONSE TIME	1–2 seconds	Fast system response times will allow storage to respond to changes in renewable operation to minimize generation fluctuations.

TRANSMISSION AND DISTRIBUTION UPGRADE DEFERRAL AND SUBSTITUTION (LONG DURATION)

The increasing demand for electricity requires additional transmission and distribution infrastructure to transport electricity from power plants to the customer. Building new transmission lines from power plants to substations and new distribution lines from substations to customers is a costly and time-consuming process. Further, transmission lines currently experience very low capacity utilization because they are designed for high reliability at peak conditions.

Relatively small amounts of storage can help to postpone or eliminate the need to build new transmission and distribution lines. The ability to store power generated during times of low demand can reduce the stress on power plants trying to generate power to meet demand, as well as the stress on transmission and distribution infrastructure. Storing electricity closer to the point of use lowers the congestion of the grid during peak demand.

The performance targets for energy storage technologies applied to transmission and distribution upgrade deferral and substitution emphasize the importance of system cost, discharge duration, capacity, reliability, and system lifetime. Safety is also an important metric for storage systems used for transmission and distribution deferral and substitution; these units must be safe to locate throughout the grid and must have cyber security protection consistent with current utility practice. These targets must be met to justify investing in energy storage technologies instead of investing in upgrades to the electricity and distribution infrastructure. If a storage technology is able to meet these targets for transmission and distribution upgrade deferral and substitution, the technology is well positioned to be adopted by the electric power industry as a more cost-effective and efficient way to modernize the electric grid and accommodate increasing electricity demands.

TRANSMISSION AND DISTRIBUTION UPGRADE DEFERRAL AND SUBSTITUTION (LONG DURATION)		
Delays or avoids the need to upgrade transmission and/or distribution infrastructure using relatively small amounts of storage		
Reduces loading on existing equipment to extend equipment life		
METRIC	**TARGET**	**SUPPORTING INFORMATION**
COST	$500 per kWh	The cost of transmission and distribution upgrade deferral and substitution should be comparable to or less than transmission costs. However, because storage can be deployed incrementally whereas transmission upgrades are generally large, storage has an advantage in present costs.
DISCHARGE DURATION	2–4 hours	Storing power for several hours will help to offset fluctuations in electricity demand.
CAPACITY	1 MW–100 MW	Transmission lines need storage capacity of greater than 100 MW.
RELIABILITY	99.9%	Storage systems used for transmission and distribution upgrade deferral and substitution need to be as reliable as transmission lines.
SYSTEM LIFETIME	10 years	While the system lifetime should be 10 years, the system must be easy to transport every 4 to 5 years.

LOAD FOLLOWING (LONG DURATION)

Fluctuations in power demand require load following, which is the changing of power output in response to the changing balance between electricity supply and demand in a given area. Generation-based resources, such as gas turbines, are typically used for this service, but the partial-load operation required by load following uses more fuel and results in more emissions than full output. Varying output also usually results in increased maintenance needs.

Energy storage technologies are ideal for load following because they are able to insulate the rest of the grid from rapid and substantial changes in net supply in comparison to demand. Many types of storage technologies can operate at partial output or input without compromising system performance. Additionally, storage technologies can quickly respond to either increasing or decreasing load by discharging or charging. Storage systems used for load following also have the potential to be used for other applications, including electric energy time shift.

The performance targets for energy storage technologies used for load following emphasize the importance of system capital cost, operations and maintenance cost, and discharge duration. The need to quickly respond to fluctuating demands also requires the storage device to have the ability to communicate and respond to the grid through the system operator. If a storage technology is able to meet these targets for the load following application, the technology is well positioned to be adopted by the electric power industry to assist with abrupt fluctuations in electricity demand.

LOAD FOLLOWING (LONG DURATION)		
Changes power output in response to the changing balance between energy supply and demand		
Operates at partial output or input without compromising performance or increasing emissions		
Responds quickly to load increases and decreases		
METRIC	**TARGET**	**SUPPORTING INFORMATION**
CAPITAL COST	\$1,500 per kW or \$500 per kWh for 3-hour duration	This cost is the upfront cost of the unit.
OPERATIONS AND MAINTENANCE COST	\$500 per MWh	A slightly higher operating cost should be acceptable if utilities provide justification.
DISCHARGE DURATION	2–6 hours	The discharge duration should be about 2 hours for capacity firming and 4–6 hours for load following.

ELECTRIC ENERGY TIME SHIFT (LONG DURATION)

The cost of electricity varies along with daily cycles of changing electricity demand. Electricity prices are higher when electricity is in high demand or when supply is low than they are when the demand for electricity is lower or when electricity supply is high. Energy storage can take advantage of lower electricity prices by charging a storage device during times of low price and then discharging this electricity when electricity prices are high. Often the extreme prices (high or low) occur not at peak times or at night, but at times of high rates of change in load or renewable generation.

Electric energy time shift is often referred to as arbitrage. But unlike arbitrage in the financial sense, energy arbitrage does not occur simultaneously; instead it involves the purchase and sale of electricity at different times to benefit from a price discrepancy. For example, electricity generated from wind at night or solar power in the morning can be purchased during these off-peak times and sold later during on-peak hours. Storage devices used for electric energy time shift, including pumped hydro plants, compressed air energy storage facilities, and large battery installations, can typically store large amounts of electricity to optimize the gain from electricity price differentials and offset the disadvantages of intermittent renewable energy sources by shifting this energy to times when it is needed most.

Performance targets for electric energy time shift focus on system capital cost, operations and maintenance cost, discharge duration, efficiency, and response time. The environmental impact of storage devices used for electric energy time shift is also an important factor to consider. If a storage technology is able to meet these targets, the technology is well positioned to be adopted by the electric power industry as a way to take advantage of the fluctuating price of and demand for electricity.

ELECTRIC ENERGY TIME SHIFT (LONG DURATION)		
Stores inexpensive energy during low demand periods and discharges the energy during times of high demand (often referred to as arbitrage)		
Accommodates renewables generation at times of high grid congestion by storing energy and transmitting it when there is no congestion		
METRIC	**TARGET**	**SUPPORTING INFORMATION**
CAPITAL COST	$1,500 per kW or $500 per kWh	$250 per kWh is a utility-set metric that may not reflect the full value of storage technologies. $500 per kWh is a sufficient metric to make storage technologies competitive with a gas turbine integrated plant.
OPERATIONS AND MAINTENANCE COST	$250–$500 per MWh	Lower operations and maintenance costs will allow storage technologies to offer the greatest economic advantages for electric energy time shift, creating greater market pull for these technologies.
DISCHARGE DURATION	2–6 hours	The price and demand for electricity may fluctuate over several hours.
EFFICIENCY	70%–80%	70%–80% is an acceptable baseline efficiency for electric energy time shift. If the efficiency of the system is only 70%, the storage system will have to incorporate other benefits to have sufficient value. The efficiency of pumped hydro and compressed air energy storage is likely to be on the lower end of this range.
RESPONSE TIME	5–30 minutes	The price of electricity will remain low or high for several hours, which decreases the need for an instantaneous response from a storage device. However, technologies with fast response can provide some frequency response and load following simultaneously with time shifting.

CHALLENGES TO WIDESPREAD COMMERCIAL DEPLOYMENT OF STORAGE TECHNOLOGIES

While the need and opportunities for energy storage are evident, a number of gaps and limitations currently constrain the adoption of grid-scale storage technologies by the electric power industry. These challenges must be overcome to achieve the widespread commercial deployment of stationary energy storage technologies and to realize the opportunities for storage in area and frequency regulation, renewables grid integration, transmission and distribution upgrade deferral and substitution, load following, and electric energy time shift applications.

The current challenges preventing the widespread commercial deployment of energy storage technologies include the following:

- Deficient market structure
- Limited large-scale demonstrations
- Insufficient technical progress
- Lack of standards and models
- Weak stakeholder understanding

These challenges are interrelated and will need to be addressed from both an individual and high-level systems approach in order to achieve commercial deployment.

DEFICIENT MARKET STRUCTURE

The current electric power industry structure divides wholesale markets into generation, transmission, and distribution categories. Since storage can support all of these functions, it is challenging to classify storage from a regulatory standpoint and assess its value in comparison to traditional infrastructure. The pricing mechanism of storage also depends on its classification. Without an accurate pricing mechanism and long-term contracts, it is difficult to ensure stakeholders that they will be compensated for the various benefits energy storage provides to the grid. This compensation is necessary for stakeholders to receive a return on their investment.

LIMITED LARGE-SCALE DEMONSTRATIONS

One main reason that storage technologies are not yet ready to be commercialized is that they lack performance data from real-world, large-scale demonstrations. Many of the current testing sites for storage cannot accommodate grid-scale systems, which limits the size and scale of simulations that can evaluate device cost, efficiency, durability, reliability, and safety. This data is needed to validate storage devices and prove the benefits of grid-scale storage. Without additional testing and demonstrations, it will be difficult to define storage applications for specific devices and convince stakeholders and regulators of storage benefits. Additionally, large-scale demonstrations are needed to help build manufacturing infrastructure for both batteries and power electronics, develop the experience needed for large-scale project financing, and demonstrate the full-scale integration of storage with grid operations.

INSUFFICIENT TECHNICAL PROGRESS

The energy crisis in the 1970s spurred the research and development of various energy storage technologies. But as oil prices stabilized, interest and funding of these projects dropped off, resulting in many technologies not reaching a maturity level conducive to commercial deployment.

The high cost of many of today's storage technologies, such as electrochemical capacitors and sodium-sulfur batteries, and the current complexity of storage technologies, such as high-speed flywheels and battery units, are major obstacles to production scale-up and integration of storage devices at grid scale. Additionally, the limited storage duration and energy capacity of technologies such as high-speed flywheels, electrochemical capacitors, and lithium-ion batteries is too short to meet the current needs of the electric power industry. Device efficiency and lifetime are also significant issues—technologies such as compressed air energy storage and traditional lead-acid batteries are not efficient enough to convince the electric power industry and regulators of the value of energy storage technologies.

To be integrated into the electric grid, storage devices also require control systems and power electronics that increase the reliability and safety of storage devices by increasing the speed and efficiency at which storage devices respond to grid signals. These system components are not currently advanced enough to ensure seamless interoperability between storage devices and the electric grid. Without sufficient power electronics, control systems, and other communication systems, even the most advanced storage technology will be unable to be reliable and secure when integrated into the grid.

LACK OF STANDARDS AND MODELS

Limited demonstration data and the immaturity of storage technologies has also led to a lack of standards and models that can help storage system developers and the electric power industry design and integrate reliable and high-performing energy storage technologies. Despite recent progress in developing dispatch algorithms for regulation service, operators lack a comprehensive dispatch strategy and operational models for different storage applications; this makes it difficult to assess the impact (e.g., forced outages from renewables integration) and benefits of grid-scale storage across wholesale and resale markets and at local and national scales.

System planners and engineers need to be able to understand the value of grid-scale storage and consistently and accurately evaluate storage integration against other supply, delivery, and demand-side options. The lack of testing protocols and simulation models prevents cross comparison and more accurate performance specifications regarding energy efficiency, cost, and other valuable attributes of energy storage systems of varying sizes and applications. Additionally, the lack of standards for power electronics, communications, and control systems and protocols poses challenges to ensuring successful and safe interoperability between storage devices and the electric grid.

WEAK STAKEHOLDER UNDERSTANDING

Energy storage technologies and devices have a substantial opportunity to transform and modernize the U.S. electric grid, but the benefits of grid-scale storage are not well understood by stakeholders. Without this understanding, energy storage technologies will be unable to achieve the support and level of deployment necessary to actualize substantial changes to the electric grid.

Much of the electric power industry, including utilities, grid operators, and energy storage developers, is unaware of the value of energy storage technologies and the applications to which they can be applied. This lack of understanding prevents the industry from demonstrating storage technologies in grid-scale real-world settings, which is critical to producing the understanding needed to validate the benefits of storage technologies (e.g., storage costs and return on investment, energy efficiency, and discharge duration) and to eventually attain widespread industry operating experience and acceptance.

The lack of industry understanding also inhibits regulators from considering energy storage. To allocate resources toward classifying storage within the generation, transmission, and distribution market structure of the electricity pricing system, regulators will require evidence of viable business models for energy storage. This model must demonstrate the potential of energy storage to capture diffuse revenue streams, modernize the electric grid, and reduce greenhouse gas emissions. If this evidence is not available, regulators will not be able to provide the resources needed to commercially deploy grid-scale energy storage.

With the industry and regulators lacking a clear understanding of the benefits of energy storage, it follows that the public may be difficult to convince. Public acceptance issues can prevent the siting of energy storage installations, such as large compressed air energy storage facilities, pumped hydro, or high-temperature battery installations. Required permitting could also make siting difficult, as installations may require complex interagency approvals and long permitting processes.

LEAD-CARBON BATTERY STACKS AT EAST PENN MANUFACTURING PLANT
DOE FUNDING FROM THE AMERICAN RECOVERY AND REINVESTMENT ACT

20-MEGAWATT BEACON POWER FLYWHEEL FACILITY
DOE FUNDING FROM THE AMERICAN RECOVERY AND REINVESTMENT ACT

ACTIVITIES AND INITIATIVES FOR WIDESPREAD STORAGE ADOPTION

Overcoming the challenges to widespread deployment and meeting the performance targets of applications such as area and frequency regulation, renewables grid integration, transmission and distribution upgrade deferral and substitution, load following, and electric energy time shift is critical to the effective integration of advanced energy storage technologies into the grid. To help achieve this goal, DOE should pursue a range of activities and initiatives in the areas of research and development; studies, modeling, and analyses; demonstrations and data collection; and stakeholder outreach and coordination. By tackling the highest priority initiatives in each of these areas, DOE, technology developers, and the electric utility industry can pursue a coherent market entry strategy for energy storage technologies in grid-scale applications.

RESEARCH AND DEVELOPMENT

Continuous basic and applied research on both new and existing energy storage technologies will provide the electric power industry with more reliable, efficient, and affordable energy storage devices. To pursue a complete systems approach, researchers also need to focus on device power electronics to ensure optimum interoperability between energy storage devices and the electric grid.

CONDUCT BASIC RESEARCH ON NEW MATERIALS AND CHEMISTRIES

The complex nature of electrochemistry offers a vast number of potential materials combinations for use in energy storage devices. Current energy storage devices focus only on a small portion of these extensive possibilities, so it is very likely that more effective, less expensive, and more robust combinations may exist. To capitalize on these opportunities, researchers need to explore new electrochemical combinations and catalysts that may be more ideal for energy storage applications. New battery couples, redox chemistries, bifunctional redox catalysts, and phase-change materials could help design next-generation technologies with the potential to revolutionize the electric power industry.

DIRECT APPLIED RESEARCH AND DEVELOPMENT TOWARD EXISTING TECHNOLOGIES

While new chemistries have the potential to expand the number of energy storage devices available, research can also help fine-tune existing energy storage technologies to make energy storage available to the electric grid in the near term. Applied research and development of existing technologies could help energy storage materials and device experts to advance storage devices such as metal-air batteries, adiabatic compressed air energy storage, and electrochemical capacitors, among others. Using more advanced materials for energy storage technologies, including lithium ion and advanced lead-acid batteries, could help increase the capacity, efficiency, and energy density of these technologies, making them more suitable for grid-scale operation.

IMPROVE POWER ELECTRONICS AND COMMUNICATION SYSTEMS

To achieve widespread commercialization of energy storage technologies, researchers need to take a systems approach by working to advance power electronics, controls, and communications components that help to integrate storage devices into the electric grid. The capabilities of these devices need to be extended so they can reduce

RESEARCHERS NEED TO ADVANCE POWER ELECTRONICS, CONTROLS, AND COMMUNICATIONS COMPONENTS THAT HELP TO INTEGRATE STORAGE DEVICES INTO THE ELECTRIC GRID.

system response time for power application to less than 100 milliseconds, decrease system cost, and heighten system reliability, which will ultimately increase the value of energy storage technologies.

Distributed and digital controls could also support the integration of intermittent renewables and the flexibility of the grid. Regardless of the methods used, collaboration between system integrators and storage device researchers and developers on storage systems is pertinent to ensure that researchers deliver devices that can meet the interoperability needs of grid operators.

STUDIES, MODELING, AND ANALYSES

To better understand the intricacies of energy storage technologies operating at grid scale, studies, modeling, and analyses can be conducted on a smaller scale to simulate and assess the impact and value of these technologies.

BUILD A MODEL TO DEMONSTRATE THE IMPACT OF ENERGY STORAGE ON THE GRID

Advanced energy storage has the ability to impact the grid in ways that have not yet been quantified due to the sheer size and intricate nature of the grid. It is critical to develop models that can be used to conduct a strategic, wide-area analysis of storage systems to investigate the effects and value of energy storage for use in grid applications. These models should assess the impact of energy storage on generation, transmission, distribution, and end-use applications and compare the cost (e.g., installation and maintenance), emissions, materials availability, efficiency, system lifetime, and cycle life of energy storage to other conventional and advanced solutions. More importantly, the models need to demonstrate the value of energy storage under varying load conditions in comparison to other types of transmission.

CONDUCT STUDIES TO UNDERSTAND SPECIFIC APPLICATION NEEDS

Studies, modeling, and analyses can help the electric power industry understand the needs of specific grid applications in order to convey application requirements, particularly cost, energy capacity, response speed, and reliability, to researchers and equipment developers. In the case of area and frequency regulation, studies should be conducted to determine the necessary response speed and minimum energy capacity required of the energy storage technologies used. Additionally, studies for renewables grid integration should quantify costs (in dollars per megawatt-hour) at various renewable penetration rates (e.g., 20%, 33%, and 40%). The results of these studies can be used to characterize the benefits of storage in specific grid applications and to formulate application standards that must be considered during technology development.

DEMONSTRATIONS AND DATA COLLECTION

An action plan that focuses heavily on real-world technology demonstrations at grid scale is essential to propel research and development efforts toward technology commercialization. Promising concepts and devices will not be able to achieve commercialization without available data that can validate their performance and demonstrate their value to regulators, utilities, and other potential owners.

DEVELOP TESTING MECHANISMS FOR UNIFORM DATA COLLECTION

The results of studies, modeling, and analyses efforts must be measured and reported in a consistent manner to enable comparison across technologies and methods. Standards (i.e., monitoring, validation, and communications) are needed for storage and other distributed energy resources to verify system costs and performance and enable uniform data collection. Developing a DOE test center and an energy storage systems screening house could help to establish the methodology and diagnostic tools necessary to assess cycle life, efficiency, robustness, and other performance characteristics of energy storage devices. Researchers can use modular testing to obtain real-world results before a test bed is available that is able to accommodate grid-scale testing. Testing obtained using uniform methods can better enable the electric power industry to develop potential dispatch strategies for various technologies in both wholesale and retail applications.

CONDUCT LARGE-SCALE AND LONG-DURATION FIELD DEMONSTRATIONS

Large-scale field testing and demonstration of various technologies in multiple applications and regions across the country are the foundation for data and analysis that will support technology commercialization. Longer-duration demonstrations can better quantify the real-world cycle life, shelf life, lifecycle cost, efficiency, impact on the grid, and performance of energy storage technologies. Large-scale demonstrations of energy storage technologies used for the priority grid applications identified earlier in this document can confirm whether a technology has the energy capacity and response speed necessary for specific applications. For example, DOE needs to support demonstrations of commercial-scale distributed battery systems (greater than 100-megawatt capacity, with a discharge duration of 4 hours) for use in transmission and distribution upgrade deferral and substitution as well as renewables integration. These demonstrations need to demonstrate the performance of the system over the battery lifetime. A large-scale demonstration of a 10-megawatt, 4-hour battery should be used to supply uninterruptible power (i.e., load management) for a data center and should also show the ease at which systems of this size can be relocated. These demonstrations should also include power conditioning systems to accurately evaluate the impact of the entire system on circuit operations. The results from demonstrations, particularly from high-risk, high-potential technologies and pilot deployments, will generate publishable data that can help communicate the capabilities of energy storage technologies and better quantify the value propositions of these technologies for grid-scale applications.

STAKEHOLDER OUTREACH AND COORDINATION

To ensure continued support of the commercialization of energy storage technologies, it is critical for DOE to engage stakeholders and communicate the value of storage by sharing advances in energy storage research, development, and demonstrations. Outreach to renewable energy stakeholders, system integrators, regulators, researchers and equipment developers, government agencies, and other members of the electric power industry can promote collaboration on technology development, which will help energy storage technologies reach market penetration more quickly and operate more efficiently and reliably once successfully integrated into the grid. Increased support from informed

stakeholders can encourage additional stakeholder experience and acceptance through the exchange of lessons learned, best practices, and demonstration results.

DEVELOP ENERGY STORAGE CLEARINGHOUSE

A DOE-sponsored clearinghouse of energy storage could serve as an authoritative source for the current status of energy storage research and commercialization. A detailed map should be developed to indicate the locations of deployed energy storage, along with technology specifications, performance data, and photographs. A database of application needs, technology specifications, and lessons learned from previous energy storage efforts should be used to assess research needs, identify technologies that meet the load needs and conditions of a particular area, and direct future energy storage research efforts.

EDUCATE REGULATORS AND POLICYMAKERS

Because regulators and policymakers develop the tariffs and rules that shape the energy storage market, it is critical to provide them with the most up-to-date and comprehensive information about energy storage technologies and applications through training, briefings, and other educational materials. To help regulators and policymakers make informed decisions about the role of energy storage, DOE should work with system operators, the Federal Energy Regulatory Commission, and the North American Electric Reliability Corporation to define and assess alternative product definitions, market rules, and dispatch signals to facilitate maximum participation and benefits from non-generation resources like energy storage. In particular, market rules should be in agreement across the United States to enable the development of a robust market for electrical energy storage.

DEVELOP BUSINESS CASE AND COST-SHARING MECHANISM

Stakeholders must understand the value of energy storage technologies and anticipate a return on their investment for storage to receive the necessary funding to reach commercial deployment. To help encourage the financing of energy storage, DOE should develop a cost-sharing mechanism that also lowers individual stakeholder risk. The partial funding of real-world deployments of these technologies can demonstrate how storage can be used to solve operational problems experienced by utilities, load-serving entities, and independent power producers. This cost sharing will drive up production and automation while also reducing manufacturing costs, ultimately allowing more storage devices to be deployed across the grid in the near term.

REVOLUTIONIZING THE ELECTRIC GRID

This workshop report will guide the U.S. Department of Energy's investments in the research, development, and commercialization of energy storage technologies for grid-scale applications. Fulfilling the research and development; studies, modeling, and analyses; demonstrations and data collection, and stakeholder outreach and coordination activities and initiatives outlined in this workshop report will help the electric power industry to address the challenges currently preventing the widespread adoption of advanced energy storage. These activities and initiatives will also help the electric power industry to capitalize on opportunities for grid-scale storage, particularly for the applications of area and frequency regulation, renewables grid integration, transmission and distribution upgrade deferral and substitution, load following, and electric energy time shift.

Energy storage technologies are the solution to meeting growing electricity demands, accommodating proposed renewable energy increases, and deferring infrastructure upgrades. Storage will reduce U.S. energy dependence on foreign imports and provide electricity with fewer emissions than ever before. The nation's ability to implement the advanced and efficient grid of the future hinges on the development and deployment of cost-effective, widespread energy storage technologies. The improved grid reliability and stability resulting from the incorporation of stationary energy storage technologies in these applications will secure dependable, affordable access to electricity for nearly all U.S. citizens in the decades to come.

25-MEGAWATT, 3-HOUR PRIMUS POWER BATTERY PLANT
DOE FUNDING FROM THE AMERICAN RECOVERY AND REINVESTMENT ACT

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