Electricity Advisory Committee

A National Grid Energy Storage Strategy

Offered by the Energy Storage Subcommittee of the Electricity Advisory Committee

Executive Summary

Since 2008, there has been substantial progress in the development of electric storage technologies and greater clarity around their role in renewable resource integration, ancillary service markets, time arbitrage, capital deferral as well as other applications and services. These developments, coupled with the increased deployment of storage technologies across the transmission and distribution system, have begun to demonstrate the ability of storage to deliver cost-effective performance in select applications and markets.

The U.S. Department of Energy (DOE) has continued to develop its strategy for technology development and demonstration. However, electricity storage is still not a "mainstream" technology routinely considered by the industry in planning, building, and operating electric power infrastructure. Numerous regulatory and financial barriers must be addressed and awareness of the technologies must be increased before storage can be widely accepted and exploited as part of the electricity supply chain as it is in almost every other industrial sector.

This document describes several areas in which DOE can address these issues:

- Stakeholder outreach and education that encompasses the development and communication of cost and performance assessments for storage technologies in different applications as well as evaluations of the impact of storage on overall system economics and societal outcomes.
- Focus on "High Impact Areas" including: holistic design perspectives on the energy logistics value chain, consideration of storage for system reliability and resilience as well as in the development of next generation control systems, development of scenarios for storage portfolio development that offer high confidence levels of overall positive outcomes, sometimes called a "no regrets" strategy, consideration of how storage might facilitate the integration of variable renewable generation and the inclusion of electric vehicles (EVs) as storage resources. Storage must be considered as part of an overall portfolio of scenarios including other new/emerging technologies or enhanced existing technologies including demand response (DR) and enhanced flexibility from conventional resources.
- Development of approaches to mitigate technology risk as a barrier to financing, insurance, and the development of storage on a commercial basis.
- Policy analysis that considers the impacts of storage on the power sector broadly including the economics of existing conventional resources that are needed to ensure adequate energy supply and grid reliability.

EAC
ELECTRICITY ADVISORY COMMITTEE
U.S. DEPARTMENT OF ENERGY

The DOE has recently issued a document, Grid Energy Storage,[1] which lays out its strategy and plans for energy storage. This strategy document is intended as a complementary document to the DOE document that addresses additional policy issues at a national level. Specific storage technologies, their state of development/technical potential, and R&D plans are not discussed in this document – these issues are well covered in the DOE document.

[1] DOE. (2013) Grid Energy Storage. http://energy.gov/oe/downloads/grid-energy-storage-december-2013

Foreword

Recognizing the Contributions of Bradford Pryor Roberts

The Energy Storage Subcommittee recognizes the contributions of Brad Roberts to the work of the Electricity Advisory Committee (EAC) and the storage industry as a whole. Brad was one of the founding members of the EAC, serving from 2008 to 2013, and was the first chairman of its Energy Storage Subcommittee. Brad led the development of the 2008 EAC report on storage which was a timely and insightful document. Many of the recommendations in that report were reflected in the American Recovery and Reinvestment Act (ARRA) legislation and in the Department of Energy (DOE) research, development, and demonstration programs over the past five years.

Brad was instrumental in the development of the energy storage market and advanced technologies. He was integral to the successful installation of 150 MW of dispatchable power across the globe. His work on benefit quantification has guided policy decisions and encouraged investment, not only in the U.S., but across the globe. Furthermore, his immense technical expertise contributed to standards development and bridged the needs of utility-grade power systems, battery technologies, and inverter-based controls. Brad was a true energy storage pioneer.

Brad was a major contributor to the work of the Energy Storage Subcommittee in 2012 and to the 2012 Storage report to DOE produced by the EAC. Those of us who worked on the preparation of this national strategy document greatly enjoyed and benefited from association and collaboration with Brad over the years. His leadership, energy, and enthusiasm will be sorely missed.

The Purpose of this Plan

The Electricity Advisory Committee (EAC), which represents a wide cross section of electricity industry stakeholders, presents here its vision for a national energy storage strategic plan. This document provides an outline for guidance, alignment, coordination and inspiration for governments, businesses, advocacy groups, academics, and others who share a similar vision for energy storage.

This strategy addresses applications of electric storage technologies that optimize the performance of the bulk power system (or 'grid') once electric power has been generated and delivered to the network, by capturing and storing electrical energy and delivering it back to the grid. Consideration of alternate methods of storing energy from fuels and other sources is outside the scope of this discussion.

This strategy aims to provide a framework of guidance for the Department of Energy (DOE) that is responsive to the broad set of conditions in technology development, business/market enterprise, and public policy that influence commercial investment in energy storage technologies. The plan's strategic activities are targeted at bringing about a minimal set of prudent, low risk investments, and accelerating the adoption of emerging storage technologies. Increasing the rate at which these technologies are deployed will provide the added benefit of further reducing their costs through endogenous technological change and learning.

A Comprehensive Vision for Grid Energy Storage

Vision

Our vision is that there will be multiple viable energy storage options for competitive and regulated markets, and for different applications and regions, which will yield positive outcomes with high confidence under a wide range of economic, regulatory, climate, and energy scenarios (sometimes called "no regrets" scenarios).

Mission

The mission is to facilitate development, adoption, and deployment of energy storage devices and systems that can meet future electric grid and consumer needs, i.e., addressing energy economics, all-hour grid reliability, system resiliency/energy security, and national policy objectives.

The Strategic Context

The Mission of U.S. Department of Energy

Any renewed approach to grid energy storage programs within DOE must recognize the scope and responsibilities of the Department defined in its mission.[2]

U.S. DOE Mission:
To ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions.

Energy:
Catalyze the timely, material, and efficient transformation of the nation's energy system and secure U.S. leadership in clean energy technologies

Science & Innovation:
Maintain a vibrant U.S. effort in science and engineering as a cornerstone of our economic prosperity with clear leadership in strategic areas.

The mission and the pillars of Energy and Science & Innovation are germane to the strategic analysis for grid energy storage programs and provide a high-level framework to direct a renewed focus on this area.

While the continuing Science & Innovation activities have been consistent with the mission of maintaining a "vibrant" effort and have put the U.S. in a position of leadership in energy storage, there are opportunities within the "catalyzing" and "transforming" dimensions of the Energy pillar which could enable the Department to more effectively meet its mission.

A Framework for Engagement

A solid plan for catalyzing a timely and material transformation of the electricity system with clean energy storage technologies must start with societal needs, relevant actors in the marketplace, and present constraints.

[2] DOE. (2013) Mission. http://energy.gov/mission. The two additional pillars of Nuclear Safety & Security and Management & Operational Excellence are less relevant to this topic and are not addressed here.

1. Taxonomy of Fundamental Outcomes (over technologies and services)

The natural evolution of technology in the electricity ecosystem has produced applications and services required for the reliable and economic operation of the system. These functions have evolved from scheduling, control, and reliability functions performed in vertically integrated utility paradigms. In many cases, the functions developed around the limitations of conventional generation resources and may have been constrained in their scope by the limits of legacy technologies. There are ongoing changes in the resource mix driven by increased penetration of renewable resources and retirements of conventional power plants that rely on older technologies. The renewable resources are in most cases inverter based without synchronously connected rotating machinery, and their output is often variable and subject to diurnal cycles that may not correlate well with system load. Renewable resources are also sometimes located on the distribution system with little or no visibility and control by the system operator and not directly participating in the energy markets. Conventional power plant retirements are driven by environmental policy and economic factors including age and performance. There are also a host of other drivers related to technology, policy, economics, and market design which influence the evolution of the resource mix such as demand response entry and exit, developments in power electronics for managing short duration variability, and regulatory policy developments related to grid modernization.

These evolving trends will have lasting impacts on the demand for market products and services. Changes in the supply portfolio could also have ramifications for system operation and reliability. In particular, the shift in the generation mix from dispatchable thermal plants to variable renewables implies an increased need for system flexibility and resiliency over time scales of seconds to hours. These increased flexibility requirements have the potential to significantly impact markets and could even challenge the operators' ability to meet existing reliability standards. There have been numerous studies of the needs for increased regulation and load following services in order to integrate variable energy resources, and these types of studies are being continued on an increasingly informed and sophisticated basis. The Western Governors' Association provides one summary of this problem and offers a useful list of measures.[3]

These challenges are further magnified by the linkage of market product definitions and system requirements to the characteristics of conventional technologies. In particular, the problems associated with adapting markets and operations to changes in resource mix and with addressing new demands for flexibility are exacerbated if markets lack the mechanisms to accurately reflect the advantages and relevant capabilities of all technologies. In addition, legacy constraints may limit the adoption of new technologies through the imposition of undue costs by unnecessarily constraining operation subject to the characteristics of conventional generation technologies. Recent "pay-for-performance" regulatory developments related to frequency regulation markets highlight one case in which these inadvertent impediments impeded storage adoption until new market signals were put in place to reflect a broader set of performance attributes. Since

[3] Schwartz L, Porter K, Mudd C, Fink S, Rogers J, Bird L, Hogan M, Lamont D, and Kirby B (June 2012). Meeting Renewable Energy Targets in the West at Least Cost: The Integration Challenge. Western Governors' Association, http://www.westgov.org/component/docman/doc_download/1610-meeting-renewable-energy-targets-in-the-west-at-least-cost-the-integration-challenge-full-report?Itemid.

conventional generators respond with relatively low precision to the system operator's dispatch signal as compared to fast inverter based resources such as some batteries and flywheels, market design rules had not anticipated the need for these changes. Market changes were ultimately motivated by the advent of newer technologies including energy storage that could deliver significant performance improvements over the conventional technologies.

Status Quo: Focus on Services

The following table, taken from DOE/Electric Power Research Institute (EPRI) 2013 Energy Storage Handbook[4], represents the range of applications and services anticipated in our electrical ecosystem. These are an illustrative set of applications and are not meant to be prescriptive with respect to wholesale market design specifically. It is also noted that these services span wholesale market design and integrated resource planning regimes.

Bulk Energy Services	
	Electric Energy Time-Shift (Arbitrage)
	Electric Supply Capacity
Ancillary Services	
	Regulation
	Spinning, Non-Spinning and Supplemental Reserves
	Voltage Support
	Black Start
	Other Related Uses

Transmission Infrastructure Services	
	Transmission Upgrade Deferral
	Transmission Congestion Relief
Distribution Infrastructure Services	
	Distribution Upgrade Deferral
	Voltage Support
Customer Energy Management Services	
	Power Quality
	Power Reliability
	Retail Electric Energy Time-Shift
	Demand Charge Management

The handbook's taxonomy is extremely helpful in adeptly evaluating the direct application of a new technology to the current service framework in the sector but it is ultimately limiting for the consideration of a new technology's true potential. As is clear in much of the terminology in the table (e.g., "spinning," "black start"), current grid services are defined by the legacy capabilities of proven but decades-old technologies.

In addition to the definitions above from the DOE handbook, recent studies have begun to explore the system needs for additional inertial response and primary governor response. These needs are driven by high penetration of inverter based resources and the benefits and issues associated with higher levels of load price elasticity in the markets that are enabled by direct dynamic price response to day ahead, hourly, and spot prices.

Storage is one of the classes of technologies that can provide increased market and operational flexibility to grid operations and markets. Together with demand side resources such as Smart Grid technologies that enable increased demand side flexibility, storage can facilitate aggregating

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[4] DOE and EPRI (2013) DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA. http://www.sandia.gov/ess/publications/SAND2013-5131.pdf.

or directly integrating distributed resources into operations and markets. Together with other technologies such as four quadrant inverters, storage can be a valuable resource for mitigating variability and providing synthetic inertial and governor response to the system as well as traditional services such as regulation, load following, and reserves. However, storage differs from conventional resources in some critical ways that limit its adoption for existing market services. For example:

- Inverter based storage technologies do not meet current North American Electric Reliability Corporation (NERC) definitions for inertial response due to the lack of rotating machinery.
- Many storage technologies are unable to cost effectively meet market rules for serving some applications over a long duration.
- Storage is inherently a zero net energy device so that either the system operator or the resource operator must provide for the restoration and maintenance of storage energy levels as explicit features of new product definitions or as implicit behavior in the market by the resource operator.

Defining new market products that exploit the capabilities of all technologies will greatly enable the innovative adaptation of the markets to changing resources, load portfolios, and behaviors. However this stands in sharp contrast to market rules that simply favor a particular new technology to accelerate its adoption. Changes in reliability standards and market design must be driven by a clear understanding of system characteristics and flexibility needs. The impacts of such changes on system performance and market efficiency must be the driving considerations of such reforms rather than the adoption rate of a particular technology or technology class. Whether particular needs are met by a regulatory fiat such as mandated governor droop capability standards for generation resources, or if they are met via market design innovations such as the ancillary service for primary frequency response implemented in the UK, the specific solutions must be developed through transparent and inclusive stakeholder processes.

Some regions and markets have begun to grapple with some of the fundamental questions necessary to address these challenges. Recent efforts have focused on the development of system flexibility definitions and requirements under different scenarios and the role of new technologies such as storage for meeting those needs. It appears that regionally distinct solutions will emerge as the various markets pursue their own approaches for addressing these issues. As new product and service definitions are developed to meet regional needs, the industry will learn what produces the best outcomes under different conditions. DOE can support these initiatives by encouraging and funding additional studies and research as part of its normal activities. When particular market and reliability innovations are ready for “proof of concept” trials, DOE can provide funding and technology assessment support as it does today in various programs. However, the linkage of conceptual innovation and proof of concept has to be done in close conjunction with system/market operators and even driven by them.

The continued development of markets and products should reflect the capabilities of all technologies, including storage. For instance, in some capacity markets, the capacity factor of variable resources, such as wind, reflects the likelihood of their availability during specified times and limits the amount of capacity that such resources can bid into the market. Although storage dispatch is not constrained due to this type of resource variability, the consideration of storage technologies in the context of resource adequacy will need to account for limits to system availability stemming from storage inventory limitations, depending upon the 'duration' of the particular storage technology and facility and its usage as applied.

The operational needs of the system operator, as articulated by the market design, will in the end be served by a mix of different resources. Each resource might have different operational characteristics. The varying operational requirements (as expressed and priced through the clearing of the various market services) will be a function of regional conditions and resource development. The resource mix/portfolio that emerges in each region will be a result of the market design/economics and policy imperatives in each region, but there is a definite supporting role for DOE in terms of funding and ongoing collection and analysis of best practices. (This is true in general, not just for storage, of course.)

Recent severe weather events and major infrastructure disruptions, such as those that occurred during hurricanes Sandy and Irene, have also focused attention on infrastructure resiliency and on the ability of the end customer or locally aggregated customers to provide their own infrastructure robustness through back-up generation, microgrid installations, or other solutions. Discussions around the resiliency benefits of local generation for surrounding customers have begun to garner increasing attention as well. These considerations will be another driver for the development of distributed resources such as storage as they increasingly become part of "normal" operations and markets. This also implies a role for the system operator in the planning and emergency operation of these resources in some scenarios.

Ultimate approval of changed reliability and market service definitions will lie in most cases with regulatory agencies at the state and federal level, especially the Federal Energy Regulatory Commission (FERC) and state public utility commissions, as well as reliability organizations such as NERC. When system operators are ready to seek such approvals, DOE can provide supporting analyses and endorsements as appropriate.

Opportunity: Empower regulatory authorities and industry participants with information on the holistic application and benefits of storage technologies and other new technologies

The power system is evolving rapidly as a result of a multitude of different forces. These include policy and regulatory mandates at the federal and state levels, and market forces resulting from rapid changes to the cost of renewable generation, demand side resources, storage technologies and natural gas. In addition, as mentioned above, severe weather events are causing disruption to electric service and many areas of the country are actively considering how they might improve the resiliency of electric service.

Power system connected storage has the potential to be a breakthrough technology in the overall utilization of the power system. However its application still faces many barriers, including most importantly, a clear and uniform understanding by regulators and policy makers, of the reliability, financial, and other benefits of storage under a wide array of system and operational conditions. The DOE already takes a leadership role in sponsoring promising technologies, but it can amplify its influence by taking a leadership role in providing a holistic analysis of how storage technologies can improve the overall utilization and resiliency of the power system. The application of these technologies may differ depending on the regulatory paradigm, notably between regions that have chosen to remain with central planning and cost of service, and regions that operate under the auspices of restructured wholesale electricity markets. The challenge for DOE is to explain the benefits of storage in a holistic manner, with specific examples of how storage may be applied in different regulatory paradigms.

2. Broad Spectrum of Stakeholders

As discussed above, there is an opportunity to more fully engage stakeholders in the research, development, and demonstration application of electric storage. On the one hand, many stakeholders stand to benefit from the new possibilities created by viable storage technologies; on the other hand, stakeholder perspectives on issues such as economics, risks, benefits, regulation, and finance barriers will differ depending on the prevailing regulatory paradigm in the various regions of the country. The table below summarizes key stakeholder communities and opportunities for engagement.

Stakeholder	Opportunity to Engage
Citizen Customers	Technology demonstrations, communications
Non Governmental Organizations	Outreach, communications, education
Retail/Demand Companies	Industry trade groups, technology demonstrations
Utilities (Investor-owned, Public Power, Cooperative, Federal PMAs and Authorities)	Institute of Electrical and Electronics Engineers (IEEE), Edison Electric Institute (EEI), National Rural Electric Cooperative Association (NRECA), American Public Power Association (APPA), technology demonstrations and forums
ISOs/RTOs	Independent System Operator (ISO)/Regional Transmission Organization (RTO) Council
Policy/Regulatory Bodies	Forums, reports, analyses, educational outreach
Renewable Developers	Trade associations, technology demonstrations
Generators	Make information available for use by ISOs, RTOs, FERC, and other parties as needed to inform stakeholder processes
Solution Suppliers	Standards groups in IEEE, NERC, etc.
Technology Suppliers	Research and development (R&D) programs, outreach to suppliers on applications and requirements
Academia	R&D programs, education
Finance Community	Loan guarantee programs, educational outreach
Engineering Community	IEEE, American Society of Mechanical Engineers (ASME)

3. Regulatory and Communication Complexities Exist

The structure of the US electric power sector and its regulatory environment create barriers to the development and implementation of a truly national strategy due to the focused roles and responsibilities of each of the subsectors as defined in law and regulatory practice. In reality, in the absence of governing federal legislation or regulations, each region of the country will apply storage technology within the governing regulatory paradigm in that region. Therefore, it is important that DOE tailor its analyses and messaging to be positively interpreted by each of the recipients in the different regions of the country. The table below attempts to summarize some of these complexities.

Constraints & Boundaries	Considerations
Federal/State	National Association of Regulatory Commissioners (NARUC), FERC, and NERC all have regulatory oversight of aspects of storage. Storage brings challenges to all three groups as well as crossing boundaries in some cases.
Planning and Reliability Organizations	NERC, RTOs, and regional groups all are responsible for assessing capacity requirements, transmission plans, and regional reliability requirements. Storage can play a role in many of the issues these groups address.
Regulated/Competitive	Market participants on the load and generation sides have opportunities to apply storage in their businesses. They could impact regulated transmission and distribution (T&D) utility operations and reliability if not coordinated.
Demand/Supply/T&D	T&D utilities have opportunities to apply storage to improve reliability and asset utilization. In doing so, they could impact wholesale markets.

Siting is an area where regulatory complexity comes into play. Federal agencies that may be involved in siting include: the Department of Agriculture, the Department of Commerce, the Department of Defense (DOD), DOE, the Department of Interior, the Environmental Protection Agency, FERC, the Advisory Council on Historic Preservation, and the White House Council on Environmental Quality. The National Environmental Policy Act lead agencies are most likely responsible for siting transmission or generation on the basis of land management. DOD and DOE have siting responsibilities depending on the location. State permitting authorities are important in siting storage on private and/or state lands. In some cases, local zoning codes may come into play as well.

Depending upon the specific technology, storage offers some combination of benefits and risks with regard to siting relative to alternative resources. While some technologies might be easier to site in a dense urban setting than a conventional generator, other systems could pose significant chemical and fire risks that would pose new siting challenges. Fire risk has been the most visible safety issue, but some storage technologies employ hazardous materials, operate at high temperatures, or are conceivably subject to potentially dangerous mechanical failures. Just as with combustible fuels, any technology that stores energy in a high density at high volumes will pose risks around the sudden release of that energy. Research is needed in several areas including: a) specific failure modes and risks presented by different storage technologies; b) standards for testing and measuring these risks; c) standards ensuring that risk management is required; and d) safety standards for deployment, siting, and operations.

The electrochemical properties of some batteries pose unique fire hazards because they generate their own oxygen for combustion and cannot be extinguished by conventional first responder means. In addition, electrochemical storage technologies are typically vulnerable to short circuit failure via intrinsic internal failure or external penetration. Such batteries require application-specific safety measures for enclosure and venting.

High Impact Focus Areas

With an emphasis on catalyzing the effective use of energy storage in the electricity ecosystem, and in recognition of the various stakeholders and constraints, there is a need for focused effort. The primary objective of this work is an engaged industry and policy/regulatory landscape mobilized by actionable insights. To that end, the following four high impact focus areas are presented as examples of how DOE programs could better fulfill the Department's mission as it pertains to energy storage.

It is important to note that it is not the intent of this document to prescribe regulatory policy or suggest that DOE undertake any policy prescriptions in the pursuit of the activities described below. It is the intention of the EAC to suggest areas where DOE can have the most impact, not through prescriptive measures, but through on-going thorough research and analysis to engage and inform through the four areas described below.

1. The Economic Viability of Storage will depend in part on the Regulatory and Policy Paradigm, and in part on the cost structure of the specific technology

Existing market product definitions and operations (in those areas of the country that have chosen restructured wholesale markets) have been developed with the limitations of conventional generation in mind (since this has been the predominant system resource). Due to the evolution of the market designs, the definitions and operations do not fully unpack and specify all the reliability attributes inherent in operating a reliable power system. This is also true with regard to the performance expectations and incentives inherent in today's market designs. A number of new technologies have emerged, including storage, which offer significantly increased performance flexibility and responsiveness to the system operator. As noted above, storage is one of several new technologies that offer benefits to the system if the planning, operations, and market paradigms allow them to be fully exploited. Technology-neutral evolution is driven by appropriately defining and valuing the market services in a manner that is sufficiently granular to ensure robust competition amongst all forms of technology able to provide the service. Notably, given the complexity of the future grid, resource performance will become a highly valued attribute, particularly under stressed system conditions.

Energy storage has been valued using a variety of mathematical and system simulation techniques, depending upon the application. Its economic value to wholesale markets is often accomplished via production cost simulations that capture the value of energy arbitrage and ancillary service provision at varying levels of sophistication and detail. Its value to transmission and distribution applications is typically measured by comparing its cost to perform a given function against competing traditional alternatives.

So far the electric utility/energy industry has approached energy storage from a technology-driven perspective. This has largely entailed defining applications and market adaptations in terms of specific performance characteristics of the new technologies. A prime example of this approach is the FERC Order 755, which is heavily influenced by the characteristics of flywheel technologies. Research and development of applications and integration strategies typically focus at the "engineering level" and on adapting existing electric supply and delivery planning frameworks and tools.

In most commercial activities, storage is one part of a logistics chain that also includes production, delivery, and consumption. This is true in just about every commercial industry including agriculture, natural gas, consumer goods, and liquid fuels. Because storage technologies in these industries are commonplace and the costs of deploying storage can be recovered by the efficiencies it creates, integration of storage is part of business-as-usual. Advanced logistics planning and operations methodologies address the problem of optimal sizing and location of storage as well as its place within the value chain. The optimization of storage in this regard is also integrated with delivery logistics and costs. Operations tools deal with inventory management throughout the supply chain and at every stage of the delivery process: at production sites, in wholesale/warehouse storage, and at retail levels near consumption.

The application and economic justification for storage depends on the situation. In some instances, where the company and system logistics designer have ownership and control of all the elements, storage can be economically justified based on the improved utilization of the overall system (e.g., retailer owned warehousing in a vertically integrated retail businesses). In other instances, private investors make investments in storage because there is an economic opportunity that allows the investor to take advantage of an arbitrage opportunity in the market or the economic necessity to smooth fluctuations in supply (e.g., peaking LNG facilities, independent warehousing facilities, warehousing owned by the manufacturer but not the retailer, or grain silos that are owned by the intermediate food producer instead of the farmer). Similar examples also exist in concept and in practice in the electric system, but the regulatory process can make the deployment of storage more difficult.

In centrally planned, vertically integrated electric systems, the planner can optimize the overall utilization of the power system through the appropriate deployment of storage if it is economic to do so and if the utility can obtain approval from the regulator. In restructured wholesale electricity markets, the economic opportunity presented to storage investors will depend on the granularity of the product definitions in the market design and the supply/demand conditions in the market and storage investments, including the opportunity for economic arbitrage. Thus, demand for the services that can be provided by storage can be influenced by the reliability needs of the system and the market design, whilst supply for grid services can be affected by the input costs to generators, storage technologies, and demand resources. Regulators and policy makers have the ability to affect both the input costs and the market design. Of course, developers of storage technologies are continuously looking for ways to lower the cost of the technology. In the case of some technologies, the manufacturer of the storage technology may be trapped in an 'economy of scale' conundrum, where there isn't sufficient demand yet for the technology to achieve widespread cost reductions. This conundrum has occurred in other parts of the electric system, e.g., solar photovoltaics (PV), and in other industries, e.g., electric vehicles (EV), leading to policy makers to provide subsidies to manufacturers, or incentives to consumers, to stimulate demand.

The electric system has a Just in Time (JIT) production and delivery value chain due to the historical economics of storage technologies relative to investments in traditional generation, transmission, and distribution. Pumped storage hydroelectric energy is still the largest amount of storage deployed by a wide margin and is among the most flexible. However, it has historically been expensive to build and raises environmental concerns. Notwithstanding that, developers are pursuing expansion/modernization of existing facilities and development of new sites. The wind and water program at DOE is developing modular pumped hydro storage, which may mitigate these cost and environmental issues. Arguably, the largest source of storage on the electric system is in the form of fuel inventory, i.e., the raw material for production, which is available on demand to an electric generator for conversion to electricity. The delivery of the generated power to the customer happens immediately by means of transmission and distribution infrastructure. As described earlier in this paper, the electric system is undergoing transformative change, which has created additional reliability challenges, and therefore, new value propositions for use of energy storage in the electric system. For example variable renewable electric generators break convention by not having the benefits of energy storage in the form of a predictable fuel source. In addition, the electric power sector has traditionally sought to achieve resiliency through power system redundancy at the bulk power system level where it has been most economic (since the costs of the redundancy, such as operating reserves or transmission upgrades, could be broadly shared by an entire region). However, storage offers the ability to achieve resiliency at *both* the bulk power system and distribution/customer levels.

Energy Storage Designed for Security and Resiliency

Energy storage studies and demonstrations have typically focused on "normal" market economic impacts and "normal" system reliability under frequent weather conditions. Customer demands for higher reliability, infrastructure resiliency, emergency power, and rapid recovery to address natural disasters and other challenges potentially create additional market need which energy storage technologies are uniquely situated to fulfill. The role of storage in providing energy security and resiliency under severe weather and other large scale disruptions has not been factored explicitly into development plans and portfolio analyses to date. A potential early adopter of such an approach is the DOD, which is developing energy resiliency and security plans, as well as technology demonstrations for its facilities.[5] The DOD is especially focused on renewables and microgrids, where energy storage has a role to play. Storage can be a source of short term mobile electric power during outages and can be one component of a resiliency solution that takes advantage of local renewable resources. DOD "lessons learned" from early installations can be combined with similar lessons learned from DOE microgrid pilots and demonstrations.

The Potential for Energy Storage to improve Electric System Performance

Grid flexibility and resiliency have become increasingly important attributes of the electricity value chain. Under a wide variety of resource development scenarios, factors such as climate change, extreme weather, grid development, fuel costs, and technological innovation will drive the needs for flexible and resilient resources and assets. New metrics for system flexibility requirements can be assessed and monitored on an ongoing basis and could conceivably be part of the development of new capacity planning or capacity markets that reflect performance and/or flexibility requirements. Storage and other new technologies could then be a factor in response to such requirements. These application-specific scenarios could also inform the development of demonstration projects and technology commercialization, focus appropriate cost reductions/performance improvement efforts, and provide a framework for the design and implementation of government policies, incentives, and resource mandates-- thereby stimulating demand for the deployment of storage and solving the 'economy of scale' conundrum.

Utility system planners and operators and their regulators are actively engaged in trying to improve the flexibility of electric system resources to deal with a wide range of operating conditions, including improved resiliency to withstand major weather events. There are typically two timeframes to consider:

1. The long term planning horizon where the planner uses a predetermined set of criteria (which will vary region to region) to ensure grid reliability (and resiliency) and in the case of wholesale markets, where the market administrator uses some form of market procurement or resource adequacy mechanism to ensure long term resource adequacy (e.g., capacity markets)

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[5] Holland A, Cunningham N, Huppmann K, and Joyce W. (2013) Powering Military Bases: DOD's Installation Energy Efforts. http://americansecurityproject.org/featured-items/2013/fact-sheet-dod-installation-energy/.

2. The short term planning and operating horizon where the system operator has to operate the system with the resources that are physically available at the moment of need

Ultimately, the concepts of flexibility and resiliency can be simply stated as the need for resource and transmission/distribution system ***performance*** under a variety of operating scenarios.

In a centrally planned system, the system planner can model the attributes of various elements of the power system and decide on the optimal resource mix and the optimal transmission/distribution configuration to achieve a desired performance outcome. In the world of restructured wholesale markets, the grid operator and planner has to signal its long term performance expectations through its long term system planning process and the market mechanism it uses to ensure long term resource adequacy. In addition, the grid operator needs to signal its day-to-day performance expectations through appropriate market pricing in the multi-settlement energy and ancillary services markets. In this world, the system operator has to operate the resources that have been procured through the market, and it cannot dictate resource outcomes. This explains why the price signal and incentives presented to suppliers of wholesale market services is so critical to ensure resource and system performance (and therefore to ensure overall system flexibility and resiliency).

The DOE can assist this discussion by analyzing and recommending improvement opportunities in the following areas: (Again, this is true of other new technologies/processes as well.)

a) Improved definitions of required system performance and resource performance under a variety of stressed system operating conditions
b) Translation of (a) into revised planning procedures for consideration by grid planners and their regulators
c) Translation of (a) into improved market product/service definitions for consideration by market designers and their regulators

The Sandia National Laboratories (SNL) report, SAND2013-4902, “NV Energy Electricity Storage Valuation,” examines how grid-level electricity storage could benefit the operations of NV Energy in 2020, and assesses whether those benefits justify the cost of storage. This study, done by SNL and the Pacific Northwest National Laboratory (PNNL), is an example of scenario analysis that could be undertaken for other such entities and perhaps for the nation. More recently, the California Public Utility Commission (CPUC) has developed “use cases” describing storage applications at different interconnection levels: transmission, distribution, and behind-the-meter.[6] As part of this work, the CPUC has developed analytical methodologies for evaluating the costs and benefits of storage in the context of these applications. This is another platform that can be built upon for the future development of these concepts. Leveraging this prior work and building upon it is a logical next step.

[6] DNV KEMA Energy & Sustainability. (2013) Draft – Energy Storage Cost-effectiveness Methodology and Preliminary Results. http://www.cpuc.ca.gov/NR/rdonlyres/A7FF0A4E-44FA-4281-8F8F-CFB773AC2181/0/DNVKEMA_EnergyStorageCostEffectiveness_Report.pdf.

Energy Storage Designed around Electric Vehicle (EV) Potential

Recent discussions on the strategic value of distributed electric storage have underscored the unique opportunity of utilizing EV batteries as grid storage resources as they become more numerous. While working examples of this application are currently limited to research projects and demonstration systems, the ability for smart meters to tap a portion of an EV battery's stored energy is technologically feasible today. A bill considered during the 2012 Kansas Legislative session specifically recognized that smart EV meters should be able to record the net energy used to discharge and recharge EV batteries, as well as the timing of those events, to settle billing accounts. While the bill did not proceed in its original form, it is an example of progressive thinking on the delivery of benefits to EV owners related to the value of stored energy.

EVs are also the focal point of discussions about fast recharge stations, battery exchange facilities, extended battery life, and battery recycling and disposal. EV batteries also play an important role in the larger issue of managing the many new control points through which distributive energy will enter the electric grid. These topics are indicative of how technological capability results in additional public policy and grid management issues being identified. These issues span the Office of Electricity (OE), the Office of Energy Efficiency and Renewable Energy (EERE), and Transportation sectors of DOE as well as linking to the Department of Transportation (DOT). The DOD is aggressively pursuing pilot programs of Vehicle to Grid (V2G)applications and may (again) provide early "lessons learned" that can be exploited. Battery life cycle concerns limit the willingness of vehicle Original Equipment Manufacturers (OEMs) to warranty EV batteries for two-way V2G applications. Modulated charging could potentially provide many of the same benefits to the grid with reduced impact on battery life. Another possibility is to reserve V2G capability for low frequency emergency applications.

Energy Storage and the Next Generation Energy Management System (EMS) Designs

The designs for energy storage systems and the next generation Energy Management Systems (EMSs) should be undertaken in a coordinated manner so as to develop products to handle the many new control points that distributed energy and distribution management systems will yield. Additionally, EMS analytic applications are cast in the same mathematics, models, and paradigms as existing system planning tools, market product definitions, and the like. Current EMS analytic applications are only equipped to handle energy storage through simple state-of-charge and charge-discharge monitoring. There are no standard algorithms or solutions in place for scheduling and dispatching storage or incorporating storage into contingency analysis. In the longer term, the very fast, controllable performance that storage technologies offer could be advantageous for applications typically not envisioned today: small signal stability control, transient stability control (i.e., relieving transmission constraints established by transient stability and enabling lower congestion), and fast contingency relief for congestion cost reductions.

2. Cogent System-Wide Cost/Benefit

Guided by a holistic perspective of our electric system, DOE can play a critical role in informing policy activity for all stakeholders.

A regional example of this type of role is exemplified by the landmark CPUC order that mandated target levels of storage to be considered in system planning by California's utilities.[7] The key elements in such a framework are:

- An agreed upon regulatory basis for defining the application(s) of storage
- An agreed upon cost benefit methodology for use in obtaining regulatory approval and ultimate rate base recovery or inclusion in energy tariffs
- Targets for storage development in planning based on an understanding of the overall system cost and benefits ("targets" as opposed to "mandates" – ensuring that storage is fully considered in planning without mandating outcomes per se)

The agreed methodologies for evaluating storage in particular "use cases" need to be transparent, peer reviewed by industry, and subsequently validated by post installation analysis of actual results.

Many emerging storage technologies face the canonical volume development/cost reduction conundrum of technology development. Achieving commercial viability depends upon increasing production volumes to reduce manufacturing costs and boosting the number of installations to spur further cost reductions through learning. This activity also builds confidence in performance. However, volumes cannot increase sufficiently until costs come down and experience is gained. A legitimate government role is to shorten the commercialization period and perhaps to make energy storage a viable commercial option today. Incentives or mandates in different applications via appropriate programs consistent with government policies for new energy technology incentives (as with PV) could be enacted until the technology matures and the optimal role and deployment level of storage becomes apparent. These are policy issues for Congress and state legislatures – DOE's role can be to inform policy makers as to the cost benefits and likely impact of such policies.

3. Risk Mitigation Frameworks

There are three key risks recognized by utilities and regulators: a) technological risks associated with equipment failure to meet anticipated warranties, b) political risks associated with higher costs to customers to replace prematurely failed equipment (i.e., the equipment is at equal or lower costs than existing alternatives up front, but its projected life expectancy is not met as a "technology type failure" and widespread premature replacement is needed), and c) environmental risk associated with technologies new to the electricity system. These risks exist even when pilot projects have demonstrated favorable performance and initial/operating costs for storage over a short to medium time frame.

Technological risks are partially addressed through DOE pilot and demonstration projects, National Laboratory testing (the equivalent of "Good Housekeeping Seal of Approval"), and manufacturers' warranties. As the EAC has previously stated, DOE should continue to increase the visibility and outreach to utilities and regulators regarding the results and larger applicability

[7] Commissioner Peterman, California Public Utilities Commission. (2013) Proposed Decision Adopting Energy Storage Procurement Framework and Design Program. http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M078/K912/78912194.PDF.

of these demonstration projects. Too often pilot projects conducted on one type of system [e.g., a small Investor Owned Utility (IOU), large IOU, municipal utility, or rural electric system] are not viewed by the other entities and their regulators as applicable to their systems. Similarly, pilot projects conducted in New England may not be accepted by Southwest entities because of weather or system operational differences.

A very real technological risk with electrical storage is premature end-of-life if the technology does not support the number/rate of charge/discharge cycles projected. This is difficult for developers and utilities to analyze given the lack of long-term historical data, and consequently conventional insurance is often prohibitive or, more likely, unavailable. Guarantees by suppliers are viewed as inadequate due to the fact that many of them are relatively new companies. This suggests that government-backed insurance as a last recourse may be as valuable as traditional policy instruments such as subsidies, tax incentives, and loan guarantees.

Political risks are more amorphous and therefore more difficult to address. In addition to the typical power sector risk aversion with regard to new technologies, the nature of energy storage and the makeup of its support base contribute to the political risks storage faces. First, many manufacturers and installers of energy storage devices are relatively new, small, and under-capitalized firms that may not be able to stand behind a warranty. Regulators, and hence utilities, are concerned that failure of a storage device will result in higher replacement power costs and the need to purchase another storage device or alternative technology. Both would subsequently result in higher costs to consumers. The failure of a major storage device would likely result in swift criticism from the media and elected officials; the ensuing political backlash would likely further slow the deployment of energy storage.

Environmental risks associated with new technologies can originate in the raw materials, manufacture, operations, and/or at end-of-life. It is important to note that in other sectors, storage technologies have well established track records for addressing this risk class. For instance, battery technologies used for other non-power-sector applications are already routinely and extensively recycled. However, DOE still has a role to play in comprehensively analyzing these potential impacts, identifying gaps, and supporting the development of appropriate mitigation strategies. In addition, it would be helpful to have some comparative analysis of current and future technologies applicable to such strategies. This work is instrumental in the continued adoption of safe, effective energy storage solutions and should be continued and expanded within DOE.

Environmental and safety risks impinge upon siting decisions and approvals. Depending upon the storage application, different regulatory agencies and other jurisdictional bodies will have the responsibility for approving standards, evaluating and approving siting proposals, and inspecting/approving installations and operations. For most new storage technologies and many applications/siting, these standards do not exist and cognizant authorities may be at a loss in how to proceed. DOE can provide leadership and technical support for standards and test development and guidelines for siting and approvals.

Both technological and political types of risk are real and act to inhibit proposing and approving the use of storage devices. Previous Energy Storage Subcommittee and EAC Reports have encouraged the development of risk assessment and mitigation models and programs.

Risk of technology and equipment failure can be modeled and quantified based on experiences with other technologies incorporated into the electric grid system and by analyzing storage experiences in other economic arenas. For example, the evolution of the performance of energy storage devices in wireless communication devices over the history of their deployment may be valuable in gauging system risks to the electric system. Operation over time of electric breakers under conditions of high and low loads may be instructive in modeling potential performance risks for energy storage devices.

While DOE should not pick winners and losers in terms of specific storage technologies, the Department can provide invaluable information about the performance of different storage technologies under varying operating conditions.

With the development of valuation models for storage that capture both operational and economic value, the risk of technological failure and equipment failure can be quantified and political risks can be mitigated by developing a shared "insurance" program through which manufacturers, utilities, customers, and DOE share in "guaranteeing" that customer costs will not exceed a predefined amount in the event of an equipment failure. Such an insurance program could take many forms, e.g., a sliding cost to the contributors based on the field experience of each specific product or a mechanism that applies only to the first 15-20 devices of each type that are installed.

While utilities are accustomed to the incremental adoption of new technologies and the minimization of risks to system operation as new systems are introduced, regulators are often hesitant to accept much risk. A program developed by or on behalf of DOE that quantifies the technological risk of adoption and provides the financial assurance that the costs to consumers will be minimal in the event of equipment failure could significantly address the reluctance of utilities and regulators to propose and approve storage devices.

Such financial instruments should be developed in cooperation with the global financial community, storage device manufacturers, system operators, utilities, and state regulators. Lloyds of London develops insurance packages for all types of maritime vessels, cargoes, and risks and the U.S. Department of Agriculture develops crop insurance programs. DOE can similarly partner with the academic and financial communities to develop risk assessment and mitigation models that the private sector can subsequently convert into affordable risk management instruments.

The development of such technological and financial risk models should be relatively inexpensive but could greatly improve the likelihood that energy storage devices will be perceived as viable and responsible investments. This is especially true if the analysis and model development incorporate assessments of the economic and operational value of energy storage for reliability and resilience, the increased capacity value of variable renewable energy resources, and increased customer productivity.

4. Policy/Regulatory Impact Analysis

DOE has an opportunity to inform key stakeholders through the analysis of regulatory policy frameworks. This work should focus not only on future potential approaches but also on the effectiveness of past approaches.

The Energy Information Administration (EIA) is one possible venue for undertaking such an analysis. In addition to the traditional technology focus of the EIA, there is an opportunity to re-frame the analysis of the EIA. Just as the EIA tracks statistics on generation construction, retirements, and production, it should begin to track information on storage system deployment and utilization.

The EAC has recommended that DOE support development of economic and operational models that incorporate storage as a means of meeting system needs and potentially displacing the need for traditional generation, transmission, or distribution assets. Such analysis should not be prescriptive with regard to market design or utility structure and should strive to inform the broadest set of stakeholders across a wide variety of contexts. This work may also assist FERC-regulated grid planners as they comply with FERC Order 1000.

The FERC, through its recent Orders 755 and 784, has taken steps to encourage the development and application of storage in the ancillary service markets. However, there are additional opportunities for regulatory policy to help spur storage development in other arenas. DOE analyses could be helpful in facilitating discussion on the following topics:

- Regulatory approaches and decisions on the treatment of storage for capacity markets, wholesale energy arbitrage, transmission congestion relief, and the provision of balancing services to enable renewables integration. Such regulatory measures need to be based on improved definitions of required system and resource performance under a variety of stressed system operating conditions.
- An open discussion on the interactions of capacity markets, treatment of storage as a “time arbitrage” resource, and overall, whether storage is a new technology in each of the domains of Transmission, Distribution, and Generation, or a new type of resource altogether, or some combination of the two. The regulatory treatment of storage and how it is incorporated in market design can have unintended consequences on the revenues available to conventional resources with attendant implications for the financial viability of those resources. This can lead to additional financial pressures on plants that rely on infra-marginal revenues, leading them to retire or to seek additional revenue streams from capacity payments. Thus a balance is needed between adapting market protocols and resource performance requirements to accommodate storage cost effectively and the overall economics of the markets and the market participants. These effects overall are not well understood quantitatively in all markets, especially those that are still grappling with capacity adequacy and capacity market questions.
- As discussed above, innovation in the US electric power sector around markets and reliability services is driven at a regional level. Adaptation to new resource mixes and load behavior is driven by actual and forecast penetrations of these technologies in each region as influenced by economics and policy. While some regions may be more aggressive in these innovations, the trends are still in their early stages and “best practices” are far from evident. Continued innovation and objective assessment of results and dissemination of lessons learned to the industry will be essential in the coming years.

Action Plan

The four high impact focus areas are described above in the context of an engaged industry and policy/regulatory landscape mobilized by actionable insights. They contain a number of potential action items that can be organized into an action plan for DOE. These action items are offered below for DOE's consideration.

Phase 1

- Review of existing studies to validate/quantify known and unknown needs for performance (flexibility and resiliency), storage valuation, and storage
- Development and implementation of Funding Opportunity Announcement Requests for Proposal (FOA RFPs) for regional performance (flexibility and resiliency) assessment and needs as described above. Such FOA RFPs should be "technology neutral" and allow alternative technological solutions.
- Development and implementation of FOA RFPs for analyzing storage investment decisions and incentive designs so as to inform policy makers responsible for and empowered to enact such policies.
- Collection and assessment of ongoing regulatory frameworks established (as an example, the CPUC storage use cases) for categorizing and valuing storage in different applications.

Phase 2

- Review of manufacturing cost issues and volume/scale factors as well as quality assurance (QA) and manufacturability issues; identification of materials science and manufacturing technology/testing gaps that DOE can address.
- Review of holistic systems design and installation issues, as well as performance experience and lessons learned.
- Development of FOA RFPs to address manufacturability and design/installation issues identified above.
- Collation of volume/scale cost factors for use in incentive design (whether subsidies, investment tax credits, or other incentive structures).

Phase 3

- Completion of regional performance (flexibility and resiliency) requirement studies.
- Completion of investment decision economics.

Phase 4

- Development of policy and incentive analyses and alternatives by state and federal authorities based on information gained and lessons learned. These potentially involve multiple regulatory bodies and legislation across various levels. DOE can play a critical role in education, analysis, and information dissemination.

Conclusion

The Energy Storage Subcommittee of the Electricity Advisory Committee is pleased to present this strategy document to the Department of Energy (DOE) for consideration as it develops its official grid connected energy storage strategy. In conclusion, the committee would like to emphasize the opportunity for DOE to meet its mission through its renewed focus on energy storage with a particular focus on providing robust analytical support for educating and engaging a broad set of stakeholders on the benefits of grid connected energy storage. In the near-term, this updated frame and broad engagement on energy storage can be directed to the four high impact focus areas: holistic electric system designs, cost-benefit analysis, risk mitigation frameworks, and policy/regulatory impact analysis.