Electricity Advisory Committee

TO: **Honorable Patricia Hoffman, Assistant Secretary for Electricity Delivery and Energy Reliability, U.S. Department of Energy**

FROM: **Electricity Advisory Committee (EAC)**
Richard Cowart, Chair

DATE: **March 18, 2016**

RE: **National Distributed Energy Storage in the Electric Grid**

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1. Executive Summary

The distributed energy storage (DES) segment of the energy storage market currently has the highest growth rate in the sector. As incentives for development and deployment have been introduced and costs have fallen, the number of DES projects both in the United States and globally has increased significantly (see Figure 1). The growth of DES is closely linked to the rapid deployment of behind-the-meter solar, high commercial/industrial tariff demand charges, demand management incentives, and self-generation incentives.

Figure 1. Planned and Deployed Distributed Storage as of August 2014

Recent announcements by major manufacturers have brought DES further into the spotlight. For example, in mid-2015, Tesla launched a DES product line and battery factory to deploy DES in large volumes. Tesla's low cost home battery pack, the Powerwall, reportedly captures and stores up to 10kWh of energy from wind or

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solar and retails for up to $3,500.[1] In the first week alone, Tesla received orders for the Powerwall worth greater than $200 million in revenue.[2] Other major manufacturers have made similar announcements with expanded DES product offerings, including Samsung[3], LG Chem[4], and Saft[5].

Due to this rapid evolution of DES, the U.S. Department of Energy (DOE) Electricity Advisory Committee (EAC) undertook a review of the DES market. Two of the EAC's subcommittees—the Smart Grid Subcommittee and the Energy Storage Subcommittee—spearheaded the review and on the basis of this assessment will make joint recommendations to DOE regarding its DES strategy and activities. Members from both Subcommittees contributed to the working group for this review.

The EAC's DES working group conducted interviews with industry experts and market participants to gain further insight into the developing DES market. The interviews were conducted in an open question-and-answer format, which allowed the expert to provide his/her perspective on DES for a broad range of topics including market drivers, product attributes, valuation of DES services, market impediments, technology limitations, interconnection challenges, interactions between DES and bulk electrical systems, control challenges, and codes and standards. Table 1 lists the experts that were interviewed for this review. In addition to those listed below, three experts from EV OEMs provided "off-the record" comments and insights for the prospects of using EVs and plug-in hybrids in the DES market.

What follows is an overview of the recommendations to the DOE – crafted by the EAC Subcommittees and informed by the expert interviews – on tangible ways in which the DOE can support DES market deployment through technology developments and technical analyses. The subsequent sections of the review highlight the current status of the DES market, unique benefits and challenges of DES, public policy implications, a discussion regarding the need for codes and standards development, and a general overview of the Distributed Energy Resources (DER) market and technologies.

For the purpose of this review, DES is defined as an energy storage element or system located at the distribution substation, within the distribution system, or customer-sited located either behind the customer's utility revenue meter or customer-sited on the utility side of the revenue meter. While electricity-in-electricity-out storage is emphasized in this review, thermal energy storage was also included in this definition. DES is contrasted to utility-scale energy storage in that it interconnects at,

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[1] *Tesla Motors. 2015. Accessed at http://www.teslamotors.com/powerwall*

[2] *Bloomberg Business. Tesla's Battery Grabbed $800 Million in Its First Week. 2015. Note: the $800 million figure includes both the Powerwall and the larger, business and utility-focused, Powerpack. Accessed at http://www.bloomberg.com/news/articles/2015-05-08/tesla-s-battery-grabbed-800-million-in-its-first-week*

[3] *Cleantechnica. 8 kWh & 5.5 kWh Energy Storage Units Introduced By Samsung. 2015. Accessed at http://cleantechnica.com/2015/06/16/8-kwh-5-5-kwh-energy-storage-units-introduced-samsung/*

[4] *Market wired. LG Chem and Eguana Announce Premium Home Battery System for North America. 2015. Accessed at http://www.marketwired.com/press-release/lg-chem-and-eguana-announce-premium-home-battery-system-for-north-america-tsx-venture-egt-2012238.htm*

[5] *Saft Batteries. Saft Li-ion batteries start rolling out to Germany's residential PV market within Bosch's hybrid intelligent energy management and storage solution. 2013. Accessed at http://www.saftbatteries.com/press/press-releases/saft-li-ion-batteries-start-rolling-out-germany%E2%80%99s-residential-pv-market-within*

and supports, the bulk electrical power system level, and is usually of a larger unit size (>5MW). DES has distinct advantages over utility-scale energy storage for size, functionality, location, and value. Many experts believe that the maximum benefits for energy storage are on the distribution system or behind the meter applications.

Table 1. Experts Interviewed for Distributed Energy Storage Market and Technology Review

DES Expert Interviewee	Affiliation	Interview Completion Date
Willem Fadrhonc	STEM	10/20/2014
Tom Weaver	AEP	11/10/2014
Melicia Charles	CPUC	10/23/2014
Tom Bialek	SDG&E	12/15/2014
Fred Fletcher	Burbank Water and Power	10/30/2014
Dan Ton	DOE	10/9/2014
Imre Gyuk	DOE	10/9/2014
Paul De Martini	Newport Consulting Group	10/9/2014
Erich Gunther	Enernex	10/6/2014
Barry Mather	NREL	10/9/2014
Bob Rudd	Solar City	11/14/2014
Jeff Anderson	CalCEF	1/12/2015

Recommendations

Based on the insights garnered from the interviews with industry experts, and in conjunction with the DES market and technology review conducted by the EAC Subcommittees, the EAC recommends the following actions for consideration by DOE:

- *Access and track lessons learned from projects and market developments of DES.* Several of the marketing groups that track the energy storage space have expressed an interest in working with DOE to develop a project database similar to one that exists for utility-scale energy storage. Given the large number of potential installations, a similar method to track small solar projects may be appropriate.

- *Develop advanced market and cost-based market models for DES.* DES is the newest element to the growing distributed energy resources (DER) market, which is currently dominated by aggregators who compile many DER installations and bid those resources into the bulk electrical markets. Expanding the DER and DES markets will require new market methods to allow smaller units to participate in either the bulk electrical market or a new DER market. Furthermore, utilities and regulators that want to incorporate rate-based DES onto distribution systems have limited models and resources to provide detailed, rigorous analysis required for rate-based considerations.

- *Develop advanced modern grid physical models for DES.* Most electrical grid physical models focus on the bulk electrical system and integrating elements into it. Existing distribution models are relatively unsophisticated by comparison and are used primarily for fault analysis and the impacts of those faults on the bulk system. Comprehensive physical models are needed for modernizing the distribution system to determine what the next generation distribution system architecture should be and the optimum role that DES might play. Most experts believe DES is critical to the next major distribution system development but the physical models are lagging behind the deployment of DES.

- *Develop operational models and verify advanced controls.* Advanced models are needed for the operation of the electric distribution system that contain DES and other distributed resource components on both sides of the customer meter. The development of control models and control methodologies is needed to fully maximize the value of DES and to make sure that the proper control methodologies for the distribution system work well with the control structure of the bulk system. It is also important to verify control methodologies and strategies in simulations on DOE supported testing platforms and in the field by using case studies.

- *Assess the applicability of existing utility-scale codes and standards, and DG codes and standards to smaller-scale distributed storage.* Where relevant, apply beneficial lessons learned and/or note any key changes needed to make the existing codes and standards (or recommendations for such) applicable for distributed storage. Continue working toward a comprehensive effort by bringing together the numerous parties working on different aspects of storage codes and standards. This action will help to ensure that DES-specific protocols (where needed) are designed in a coherent, streamlined fashion and that new devices and subcomponents are designed in such a way that enables them to be immediately interoperable and capable of communicating with a broad range of other devices and the system at large.

- *Further leverage the DOE's unique role as an unbiased arbitrator with technical expertise.* DOE can be particularly helpful in facilitating conversations (i.e. workshops) around the more "sensitive" areas of standards, codes, and regulatory development. This could include, for example, topics such as performance evaluation, monetizing services, a separate asset class for storage, and other relevant areas. Given DOE's technical expertise in conjunction with its unbiased position, it can play a vital role in this process.

- *Assist in the deployment of new standards and codes*. DOE has a role to play in the education and deployment of new standards and codes. This is particularly true at the state and local levels where resources to track and implement new standards and codes are limited.

- *Develop technologies that increase the performance, cost effectiveness and safety factor of DES systems.* DOE can play a leading role in developing new technologies at the material, product, and system level that improve all aspects of DES. As DES is deployed in integrated environments that are co-located with critical assets (i.e. people, equipment), it is essential that new technologies are developed to reduce the risks associated with its deployment.

2. Current State of Distributed Energy Storage

Energy storage has long been recognized as a potential "game changer" allowing the power system to reflexively adjust to the limitations dictated by the laws of physics by adding a new dimension to energy delivery that is not currently available. Presently, the inherent nature of electricity necessitates that the power system constantly balance supply and demand. Storage would provide arbitrage and other opportunities by allowing users to accumulate power at a certain time for use at a later time. This "warehousing" possibility would add value to the power system by enabling increased use of variable resources, enhancing grid reliability, and delivering digital grade power where needed. There are several types of DES, including: electrochemical (e.g., batteries); thermal (e.g., hot or cold water, ice, eutectic salts); chemical (e.g., hydrogen); or kinetic (e.g., compressed air, hydro.) While electricity-in-electricity-out storage is emphasized in this review, thermal energy storage was also included in the definition of DES as used here.

This review focuses on electrical energy storage that is distributed and grid-connected on either side of the customer meter. This section provides an overview of the current state of DES and focuses specifically on recent activities and the corresponding impact on utilities, as well as key research questions driving the market. Subsequent sections address a broader range of current and future considerations as well as benefits and challenges posed by DES.

Current State

Distributed, grid-connected energy storage can improve the reliability and resiliency of the power delivery system—in addition to reducing overall costs—if developed, designed, and deployed appropriately. Further, storage can make the grid more flexible by providing a buffer between generation and loads so as to reduce the strain on grid assets and allow the grid to accommodate more variable renewable energy and many new consumer loads. In this way, storage provides valuable flexible capacity, and DES can provide local flexible capacity closer to load centers. In some cases it can do so more cost effectively than traditional status quo solutions such as gas-fired peaker plants. Storage can also make the grid more resilient by supplying ancillary services such as frequency regulation, and temporary local power source or sink, thereby augmenting transmission and distribution architecture and operations. Accordingly, it can reduce overall costs by deferring the need for investments in grid upgrades, and provide an innovative element for operational optimization.

Because of the increasing demand for clean, reliable, and low-cost electricity provided by otherwise variable resources, the value of grid storage is greater than it has ever been. Energy storage may provide fast response to second-to-second ramps in the supply or demand of electricity, as well as shifting larger amounts of energy through time to balance generation and load. Energy storage may increase the reliability and resiliency of the grid by providing temporary local sources of electricity that augment the transmission and distribution network. Energy storage may also reduce the potential for future rate increases by allowing deferral of grid upgrades and increasing asset utilization on the grid. However, grid storage still faces significant technical, economic, and regulatory challenges, which may be surmounted by a coordinated effort between industry, government, and other stakeholders.

Ultimately, distributed, grid-connected storage may change the dynamic of utility operation and business model by allowing electricity to be “warehoused.” Similar to how refrigeration completely transformed the food industry by introducing inventory at every stage in the supply chain, so too can storage impact the utility industry by acting as an inventory of electric energy on the grid, adding a buffer to what is otherwise perhaps the ultimate just-in-time production and delivery system.

Recent Activities and Impact on Utilities[6]

In February, the Rocky Mountain Institute published a paper on “grid defection,” which raised the question of whether grid-connected energy storage will fundamentally disrupt utility business models.[7] Subsequently, several other financial institutions performed less sophisticated studies that suggested the threat was imminent. In May, Barclays downgraded electric utility bonds on threat of solar and storage.[8]

In reality, storage is unlikely to pose a serious threat to utility businesses in the near term. The often overly hyped scenario of storage + solar/distributed generation (DG) causing massive grid defections is unrealistic because there are many reasons for customers to stay connected to the grid itself, even if they do have storage + DG installed on site. The grid is a valuable resource and with the combination of storage and DG there is now the possibility for customers to participate directly in wholesale markets and/or enter into long term contracts with their local distribution utility to monetize more of the benefits that customer-sited storage can provide. This is already being done in California (for example SCE LCR Procurement). Rather, storage presents a unique opportunity for utilities to deploy an amazingly flexible asset *in partnership with their customers and third parties* to increase reliability and lower the cost of grid operations for all ratepayers.

While the size of the consumer market is unclear, many early adopters want the benefit of reliability from having storage on-site to ride through outages[9]. Apparently, this is true even when the outages are relatively uncommon and there is little monetary loss. However, the reliability/resiliency value of storage is highly variable, complicated, and largely unexplored.

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[6] *Electric Power Research Institute, EPRI, based on a compilation of EPRI presentations on energy storage by Haresh Kamath and colleagues. http://www.epri.com/Our-Work/Pages/Distributed-Electricity-Resources.aspx*

[7] *Rocky Mountain Institute, The Economics of Grid Defection, 2014. Accessed at http://www.rmi.org/electricity_grid_defection*

[8] *Barrons, Barclay's Downgrades Electric Utility Bonds, Sees Viable Solar Competition, 2014. Accessed at http://blogs.barrons.com/incomeinvesting/2014/05/23/barclays-downgrades-electric-utility-bonds-sees-viable-solar-competition/*

[9] *Washington Post. 2015. http://www.washingtonpost.com/business/economy/if-the-industry-makes-its-connections-your-next-home-may-run-off-a-battery/2015/04/25/c4a68482-de00-11e4-a500-1c5bb1d8ff6a_story.html*

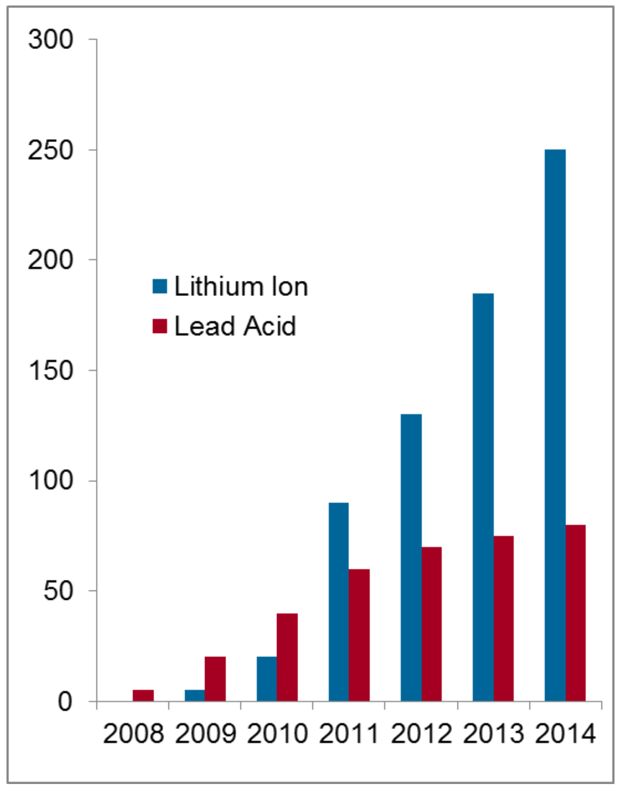
Growth Potential

The grid today operates without a substantial amount of energy storage. Worldwide, only a minimal percent of generated electricity is stored. Most of this storage capacity is interconnected at the bulk grid level. Figure 2 illustrates the total deployed grid storage worldwide as of July 2014, based on total MW installations in each respective year for two technologies (lithium ion and lead-acid based storage systems). This is not to imply these are the only technologies DOE should be tracking or developing, it is simply an indication of the growth of the market.

These percentages could change dramatically in the coming years. Storage technologies are improving, while costs are falling. Researchers have applied technological advances in materials, control systems, and power conversion to improve all storage technologies. Historical challenges of technical performance, life-spans, and efficiency are increasingly being overcome (however, grid-ready technology solutions are the exception, not the rule). Similarly, the economics of energy storage are improving as are value streams. The industry is beginning to address regulatory challenges by clarifying definitions and developing a framework for evaluating storage on today's grid while tools for understanding the value and grid impacts of storage are still in development.

Additionally, deployment of grid-connected storage continues. There has been an expansion in installations for frequency regulation and other ancillary services. The customer-side of the meter installations is also expanding, as storage companies aggressively market products to end-users.

Figure 2. Lithium ion and lead-acid-based storage systems installed worldwide (MW).



Source: EPRI and USDOE Estimates

Lithium ion, as a recently popular example (see Figure 2), has a significant advantage as being the breakthrough storage technology for distributed grid connectivity. Historically, technology adoption has relied on early adopters willing to pay premium prices to gain a significant advantage. But utility-scale storage technologies have few early adopters or even early majority participants. This raises the question as to how developers achieve scale in a market without the traditional incentives. Products with other, non-utility markets will initially do better in utility applications because they are likely to achieve scale more quickly and have a track record. In addition, once utility storage applications are established with one technology, other technologies will find it easier to follow.

Lithium ion is a compelling storage technology for distributed grid-connected applications but has some weak aspects. Cost for long-duration storage is still quite high since at very large scale, lithium ion becomes bulky and potentially dangerous[10]. In addition, material costs and lifecycle become issues as the number of installations increases. More scalable technologies may eventually become more compelling, including flow batteries, aqueous intercalation, compressed air, and hydrogen.

Thus far, most commercial utility installations of energy storage are designed to provide ancillary services. Looking toward the future, frequency regulation markets, especially, are highly lucrative, but they are also very small. In the meantime, storage designed for frequency regulation and other markets will have impacts on utilities. State and federal agencies are being lobbied for the right to interconnect directly to distribution with simplified interconnection studies.

Unknown Factors and Challenges

Grid deployment, integration, operations, maintenance, and disposal are still major unknowns. Deployment of storage and Distributed Generation technology outside of an integrated grid framework can result in substantial additional costs and have limited benefits. Fortunately, the consumer electronics and automobile industries have invested significant capital and effort into developing and manufacturing better batteries for their products. These investments will carry forward to improve grid-connected technologies.

While some storage technologies are mature, turn-key storage solutions are still nascent. Many storage technologies have relatively short useful lives. Battery lifetimes are measured in years, while traditionally grid equipment is expected to have decades-long life expectancies. As with most every other energy technology, energy storage experiences efficiency losses during operation, often referred to as its 'round trip efficiency'[11]. Such round trip efficiency losses can be considered the "cost of doing business", and are factored into specific applications. In addition, many of today's grid analysis tools are not well suited to analyze storage.

Monetizing storage can be difficult, as benefits accrue to many entities in multiple ways, and not just to the owner. Some of the economic benefits flow from certain regulatory challenges. Existing regulations are built around the just-in-time delivery framework of today's grid and do not account for many of the values of storage**.** Storage does not fit neatly into the existing categories of generation, transmission, distribution, or load asset. A separate asset class for energy storage is recommended to make it easier to monetize all of the value streams.

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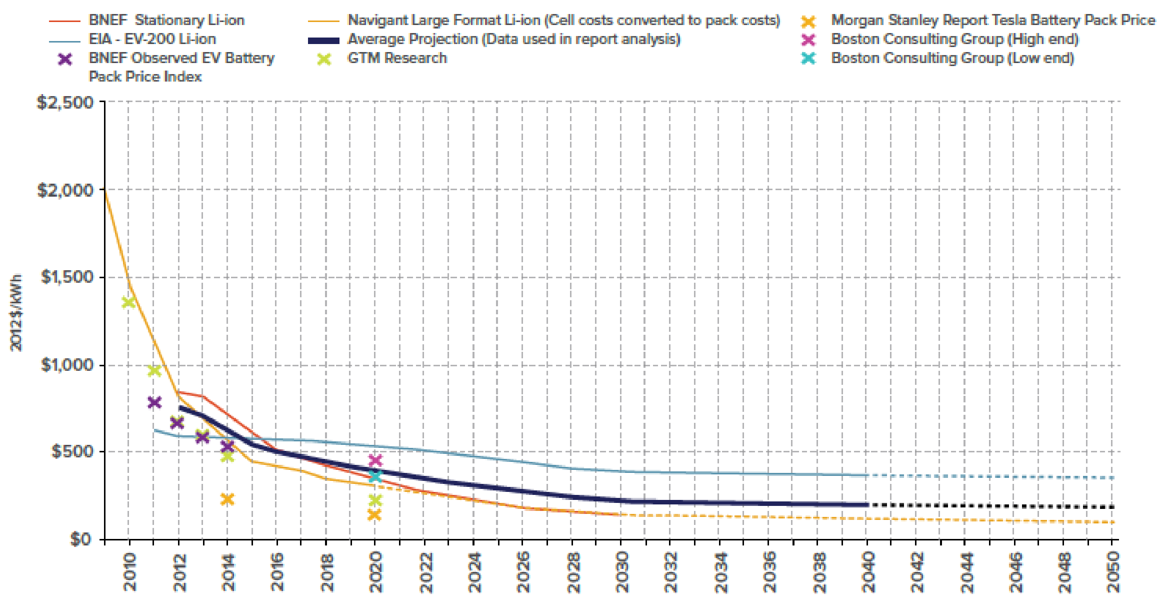
[10]Electrochemical Society. 2012. http://www.electrochem.org/dl/interface/sum/sum12/sum12_p037_044.pdf

[11] Examples of other technologies efficiency losses include degradation of PV output due to ambient temperature, 'heat rate' variations and resulting generation output variations from fossil generators depending on make, model and operational requirements. (more cycling of fossil plants results in less efficient fuel conversion)

A few companies are now producing and deploying energy storage products with major commercial and industrial potential. These products seem to be well-integrated, highly reliable, and have sophisticated control systems. Cost is still an issue but is coming down quickly; see Lithium Ion battery pack prices example in Figure 3.

Figure 3. Lithium Ion Battery Pack Prices: Historical and Forecasted



Source: Rocky Mountain Institute, Economics of Load Defection Report

Much of the improvement in lithium ion batteries has been driven by plug-in electric vehicles, with 415,241 vehicles sold in the US as of December 2015.[12] A recent Nature Climate Change report found that as of 2014 industry-wide cost estimates for electric vehicle batteries was roughly $400/kWh but the cost of battery packs used by market-leading manufacturers was closer to $300/kWh.[13] Tesla is building a much-heralded plant that will result in further cost reductions. Scale is dependent on vehicle *and* stationary markets and Tesla is not alone in investing in capacity.

Research Driving Development

The key research question dominating the storage industry is "How can we create better, longer-lasting, and more cost-effective storage technologies?" Numerous entities are undertaking technology research

[12] Vehicle count based on HybridCars.com count of U.S. sales of plug-in vehicles (BEVs, PHEVs, EREVs) from December 2010 through the end of December 2015. Accessed via http://www.pluginamerica.org/. All case studies and examples will be updated to reflect information timely for the final version.
[13] Nature Climate Change 5, 329–332 (published online March 2015). http://www.nature.com/nclimate/journal/v5/n4/full/nclimate2564.html

to address these issues including many universities and national labs funded by the DOE Office of Electricity and Energy Reliability as well as programs such as Advanced Research Projects Agency-Energy (ARPA-E). Commercialization strategies for these technologies are also important; however, at present, most commercialization is occurring overseas. DOE can assist by developing a more accurate understanding of when and how storage can best bring value. Better grid analysis tools can determine sizing, deployment, and use of storage for maximum value. Tools are in development by a number of organizations, and results are now being observed with interest by regulators.

Additional research is needed to determine what the best practices are for installing and operating storage on the grid. Improvement in storage hardware is possible only through more experience with deployment and operation of storage systems. State and federal agencies are funding many initial deployments, which are highly leveraged through investment from utilities, storage developers, and research organizations such as EPRI. EPRI is coordinating a cross-industry forum called the Energy Storage Integration Council, a technical working group that brings together utilities, storage developers, analysts, and government agencies to facilitate the development of safe, reliable, and cost-effective storage solutions.

Just as the National Renewable Energy Laboratory (NREL) has tested wind turbine components (and completed turbines) provided by manufacturers for performance, longevity, generation capacity, and other factors, and Sandia Laboratory has studied solar equipment performances, so too should a DOE Laboratory develop similar testing protocols and devices for energy storage. Whether it is utilities or consumers interested in DES, it is vital for potential purchasers to understand the characteristics under which storage device performance is maximized (e.g., weather), anticipated life charge/discharge cycles, and other empirical factors. An impartial, objective DOE Laboratory report delineating performance characteristics and developing the modeling tools necessary for utility, third party, and consumer analysis of alternative storage technologies capabilities, reliability, cost-effectiveness, etc. will better enable grid operators and consumers to integrate such devices into their electric systems.

3. Benefits and Limitations of Distributed Energy Storage

As noted throughout this review, DES provides significant potential for improving the reliability of the electricity grid, the viability of variable generation, and flexibility for utilities and consumers. However, there are still numerous challenges posed by DES, as well as challenges to DES market development. To fully realize the benefits of DES and effectively address the challenges, several key logistical and technical aspects of DES must be taken into consideration. These specifics are discussed below.

Locational Issues

DES provides some important locational differences compared to utility-scale storage. By its nature, DES tends to be deployed closer to the electricity consumer. Due to this locational reality and the smaller scale of DES (having capacities in the kW or single-digit MW range verses utility-scale with unit capacities at a MW or GW scale), there are important considerations regarding the physical characteristics of DES.

Differences Between Large-Scale and Distributed Storage

In addition to scale differences, the distributed nature of DES both requires and engenders certain technical qualifications. Most importantly, the tendency to deploy DES close to the end customer makes some technologies less practical for such applications. For instance, most current pumped hydroelectric and compressed-air energy storage technology concepts could not be practically deployed in the DES setting due to their geological requirements. However, there are some emerging products and technologies that appear to address these constraints.[14] Moreover, to be economically viable, these technologies typically must be developed at capacity scales that are greater than any practical DES deployment.

DES also has some important technical necessities based on the possible applications that a deployment could be used for. Some of the most important technical requirements are summarized below.

- *Energy and Power Capacity:* The different potential applications of DES have varying capacity needs. Generation shifting and capacity deferral services, for instance, tend to require high energy capacities. Some ancillary services (e.g., frequency regulation) are more dependent on having high power capacities that can be sustained for short charging and discharging durations.

- *Efficiency:* The roundtrip efficiency of a DES system is of course important for most applications. Moreover, some DES applications (for instance, generation shifting and emergency uses) also can be sensitive to the self-discharge rate of the technology. These types of applications may require energy to be stored for a prolonged duration of time, for which technologies with high self-discharge rates are not well suited.

- *Cycle life:* The ability of a DES technology to cycle its state of charge frequently many times is important for some applications. Frequency regulation requires relatively constant charging and discharging, and technologies with limited cycling lifetime ability are not well suited to this type of application. Generation shifting, as a counter example, typically only entails one charging/discharging cycle per day. Another important consideration is how well a technology adapts to deep cycling. Emergency uses may require infrequent deep discharges of the DES. Some technologies suffer extreme degradation with this type of duty cycle.

- *Power and energy density:* The power and energy density of a storage technology is important exactly because of the siting of DES near the end customer. Extremely low-density technologies

[14] *GreenTechMedia. 2015. http://www.greentechmedia.com/articles/read/sustainx-to-merge-with-general-compression-abandon-above-ground-caes-ambiti*

may not be suitable for uses as DES, due to physical space restrictions in an end customer building or attached to a pad-mounted distribution transformer.

Criteria Impacting Location Selection

A selection of ownership structures could be used for DES, a very important consideration in making DES economically viable. As discussed in the following section, *Value Streams for the Grid and Consumers*, the ability to capture the value associated with different DES applications is dependent on a number of factors. These include the presence of restructured wholesale electricity markets (as opposed to a DES deployment in the service territory of a vertically integrated utility), retail price structures, and the ability to design contract or incentive mechanisms for some DES applications.

If the correct combinations of restructured electricity markets (and the associated price signals), appropriate retail pricing, and innovative contract design are not available, the issue of capturing the value of DES applications can be surmounted through ownership structure. For instance, generation shifting by a DES system owned by an end customer is only economically viable if the customer is exposed to time-variant retail prices or rates. Without such a pricing structure, this application could be made viable by the utility owning the DES asset and having the correct contracting structure in place to incentivize the end customer to allow the DES system to be installed in his or her building. Further examples of how the value capture of different DES applications is affected by market design, retail pricing, contracting, and ownership structure is provided in the following section, where different value streams of DES are discussed in more detail.

While the DOE cannot advocate for a specific technology, manufacturer, planning model, etc., it has an invaluable capability of providing information, techniques for ultimate customers (e.g., PUC Commissions, utilities, consumers, third parties) to evaluate alternative technologies for appropriateness, cost-effectiveness under specific conditions, and integration modeling tools.

Value Streams for the Grid and Consumers

Depending on its use, DES offers a number of value streams. These benefits can accrue to the bulk power system, the end consumer, or to society at large. The uses that a DES deployment provides may also depend on who makes operational decisions. It should be noted that the value does not necessarily accrue directly (or only) to the device owner. For instance, an electric utility may install DES systems that are used primarily to the benefit of end consumers. In other instances, an end consumer may install a DES system that provides power system services, for which it is remunerated through retail prices or other contracting arrangements.

These potential services are classified into six broad categories and summarized in the following section. As appropriate, how these services are typically valued in the system through wholesale or retail pricing mechanisms is also explored. An important issue is that some of these services are not priced efficiently.

Moreover, current regulatory and market design practice makes it difficult for some combinations of services to be properly remunerated. These issues are discussed in more detail in the following section: *Section 4 - Public Policy and Market Practice Implications*.

Generation and Load Shifting

Generation and load shifting was and remains the primary use of large-scale energy storage deployments. Although conceptually the same, the actual operational practice of this application differs slightly between restructured electric power systems and those that are served by a vertically integrated utility. In the vertically integrated paradigm, the utility stores excess energy during periods in which the marginal cost of producing energy is low and later discharges the stored energy when the marginal cost is high. In doing so, there is a cost savings to the power system and a benefit to society at large because high-cost generation is displaced by lower-cost generation. These benefits translate into cost savings for consumers as well.

In a restructured market, storage is used in the same manner, except that charging and discharging decisions are made on the basis of market energy prices. In a restructured market, this application is occasionally referred to as energy arbitrage, as the storage plant is arbitraging differences between on- and off-peak prices. If market energy prices reflect marginal costs, these two paradigms should result in similar (ideally identical) operational decisions.

The energy arbitrage concept can be extended to DES, although doing so depends heavily on market and contract design. It is important to note that an end customer that pays time-invariant retail prices (which is true of many retail customers in the United States) has a strong *disincentive* to use DES for generation shifting. This is because using DES for generation shifting would result in a higher retail cost to the customer, due to higher net energy demand owing to energy losses from storing and discharging energy. This outcome occurs despite the fact that if DES charging and discharging are timed properly, it could provide the same benefits as a large-scale storage plant that has its operations optimized against marginal generation costs or wholesale energy prices.

While residential customers may acquire DES capabilities for political, social, or economic reasons, larger commercial customers (e.g., big-box grocery stores) are likely to be interested because of reliability, cost, and political reasons. Most of these stores have back-up diesel generators that may conflict with regulatory or popular political interests. Storage devices will be more attractive and may provide opportunities to monetize ancillary, micro-grid reliability, and other service options. DOE guidance in terms of how regulators and utilities should evaluate such technical and monetization capabilities will be important. Customers will seek to profit from DES technological capabilities, the DOE can help regulators and utilities understand how overall system reliability, resilience, performance, and environmental responsibility can be enhanced through responsible integration of DES.

One way to make DES for generation shifting viable is to introduce some form of time-variant retail pricing. This could take a simple form, such as time-of-use rates, demand charges, or critical-peak pricing, or a more sophisticated design such as real-time pricing. An important issue to note, however, is that the extent of benefit afforded by DES (relative to a storage device that has its operations optimized against marginal generation costs or wholesale energy prices) will tend to depend on the temporal granularity of the retail price signals provided. For instance, a two-tiered time-of-use tariff incentivizes charging at any point during the low-price period and discharging at any point during the high-price period. While this should provide some benefit to the system, it will tend to be less than what would be provided by optimizing DES charging and discharging against price signals that reflect real-time wholesale prices.

Time-variant retail pricing relies on the end consumer making DES charging and discharging decisions to produce the system benefit. An alternative is to have the DES system managed directly in a more centralized fashion. For example, the consumer's electric utility or a load aggregator could manage DES use on behalf of the consumer. An advantage of this model is that it can be employed without the need for any retail price changes. An example of this model is a series of thermal energy storage systems installed in consumer buildings by the Los Angeles Department of Water and Power (LADWP). The end consumers retain a time-invariant retail price. LADWP manages the use of the DES systems installed in the consumers' buildings and provides each one with a financial incentive for allowing the installation and use of the system. More broadly speaking, this model could see DES used with other demand-side management and demand response programs. For instance, a DES system could be combined with an air conditioner-cycling system to manage an end consumer's net load, making the load profile more favorable to the overall system.

Capacity Deferral

Another application is to use energy storage to defer a generation, transmission, or distribution capacity investment. These three forms of capacity deferral are functionally similar. In the case of generation capacity deferral, storage is charged when there is excess generating capacity available and discharged when generating capacity is scarce. If sufficient capacity is available, this use of storage alleviates the need to add generating capacity to the system, reducing the system's capital cost. This use of storage is typically an ancillary benefit of generation shifting. This is because marginal generation costs or energy prices tend to be low when the system has excess capacity available, and high when generating capacity is scarce. Thus, this use of storage can also reduce system operation costs (in addition to its capital-cost benefit).

Because this use of storage is closely related to generation shifting, the models discussed above, in the section on Generation and Load Shifting, allow for generation shifting in the vertically integrated or restructured paradigm and could be used to provide this benefit. The same issues concerning retail energy pricing arise with generation capacity deferral. If a consumer is exposed to time-variant retail prices that convey capacity scarcity, this should provide the consumer with the correct incentives to provide generation capacity deferral. Otherwise, direct control mechanisms, potentially combined with contracting arrangements, such as in the LADWP thermal energy storage deployment, would need to be utilized.

Properly located storage can also provide benefits in deferring transmission or distribution capacity investments. For both of these use cases, the storage device must be sited at a location in the network that sees a binding transmission or distribution constraint. Energy is stored when the capacity constraint is non-binding and is later discharged when it is binding to relive the constraint. Transmission capacity deferral could potentially be incentivized using the same methods discussed for generation capacity deferral. In the vertically integrated paradigm, the integrated utility would charge a properly-sited storage device when the associated transmission constraint is non-binding and discharge stored energy when it is binding. The utility could further determine where in the network to site storage facilities to relieve transmission constraints.

In the restructured case, most wholesale markets in the United States produce locational marginal prices (LMPs). LMPs reflect the effect of binding transmission constraints on the marginal cost of delivering energy to different locations within the network. If storage is used in a restructured market to arbitrage diurnal LMP differences, it implicitly relieves a binding transmission constraint whenever it is discharged to earn revenue from a high LMP. Moreover, a storage developer may opt to site a storage device at a location within the network that tends to have large differences between on- and off-peak LMPs, to capture higher profits from energy arbitrage. In doing so, the device is being sited at a location in the network that tends to have binding transmission constraints that the device can relieve.

Incentivizing distribution relief is more difficult in the restructured market paradigm. This is because no markets currently produce LMPs or an analogous type of price that conveys distribution capacity scarcity. Thus, the use of DES for distribution relief has so far been limited to deployments by distribution utility companies. This can either take the form of DES deployed in an end customer's building, as in the case of the thermal energy storage systems deployed by LADWP, or a larger-scale deployment, for instance at a distribution substation. An example of this latter case is a NaS battery deployed by American Electric Power in a part of its West Virginia service territory to defer a distribution transformer investment. In all of these cases, DES deployment and use for distribution deferral would be undertaken by an integrated utility that incorporated DES into its investment and operational planning processes.

Ancillary Services

A third set of applications is to use energy storage to provide ancillary services. Indeed, much of the recent “merchant” storage development in the United States has been batteries and flywheels built to provide frequency regulation in restructured electricity markets, including in PJM and the New York ISO. This is evidence that restructured electricity markets are providing price signals for competitive energy storage to enter the market and provide high-value services.

Using storage for ancillary services reduces the need to reserve capacity from a conventional generator, which often results in the generators operating less efficiently. Moreover, using conventional generators for ancillary services increases wear and tear, due to the need to cycle their output up and down. An additional benefit of using storage for ancillary services is that many storage technologies provide a much faster response than conventional generators. In sum, these benefits of using storage for ancillary services result in reduced generation costs (from operating generating facilities more efficiently) and reduced capital and maintenance costs (from reduced cycling of conventional generators).

There are several types of ancillary services, and an important distinction between the types is whether the value of the service can be transparently determined. Frequency regulation and contingency reserves (*e.g.*, spinning, non-spinning, and black start reserves) are priced in all of the restructured electricity markets operated in the United States. These prices provide incentives for storage to enter the market and provide these services. The flywheel and battery storage systems that have been purpose-built in the PJM and New York ISO footprints demonstrate that this model of incentivizing storage works. FERC order 755,[15] which requires ancillary service payments to reflect how well a resource follows the system operator's real-time dispatch instructions, bolsters the incentives for storage. This is because storage typically has a better response to the ancillary service signal compared to many conventional generation technologies.

Associated with the discussion of the other value streams for DES is an important question regarding ancillary services and whether a DES device has exposure to wholesale ancillary service prices. Retail prices do not normally unbundle ancillary service costs from the cost of energy service. Moreover, a DES device may be too small to directly participate in the wholesale market. These issues could be overcome using the same types of contracting approaches discussed for generation shifting and capacity deferral.

In a vertically integrated utility, the value of frequency regulation and contingency reserves can be implicitly determined from the utility's unit commitment and dispatch models. These models include constraints that the generators committed must have sufficient excess capacity available to meet some minimum ancillary service requirements. The value of ancillary services from storage can be assessed by allowing storage plants to satisfy the ancillary service constraints. Vertically integrated utilities rarely "publish" ancillary service cost information. Thus, using DES for ancillary services in the vertically integrated utility paradigm is currently only viable with direct utility involvement.

A major advantage of DES, compared to utility-scale storage, is the ability to locate the systems at key locations to support loads and provide critical volt-ampere reactive (VAR) support and improve power quality. Most DES systems are capable of delivering both real and reactive power. Reactive power is essential in voltage regulation and/or in supporting a large load, such as motors and compressors. Voltage regulation and VAR support is needed on a localized basis both in locale and time frame. Most bulk systems do not provide adequate support to the distribution system in this regard and this type of support is difficult to obtain from a centralized system. For example, providing voltage support on one

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[15] Federal Energy Regulatory Commission (FERC), Frequency Regulation Compensation in the Organized Wholesale Power Markets, 2011.Available at: http://www.ferc.gov/whats-new/comm-meet/2011/102011/E-28.pdf

line may cause over voltage in another part of the grid. By providing localized voltage regulation, the bulk system can focus on delivering power in the most efficient manner possible.

Similar to voltage regulation, power quality is also very difficult to obtain from the bulk system. Excellent power quality on the bulk system does not guarantee good power quality at the distribution system. Many factors affect power quality and many of those factors occur at the distribution level. DES may be uniquely qualified to improve power quality on the distribution system and therefore to the loads being served. Most power quality issues are related to over and under voltage events which can be addressed through localized voltage regulation provided by DES. Another power quality factor is signal distortion and signal interruption (losing a cycle or two). DES can provide methods to actively filter the power signature to minimize the effects of signal distortion and interruption. Other aspects of power quality are covered in the following sections, but it is important to note that a significant segment of benefits associated with DES are in the area of voltage regulation and power quality. It is difficult to compute avoided cost/values of voltage regulation and power quality services.

Reduced Transmission and Distribution Losses

Storage can also provide benefits in reducing transmission and distribution losses; these losses are proportional to the square of the current flowing over the line. When storage is used for transmission or distribution capacity deferral purposes, it reduces the line loading during peak-load periods and increases loading during off peak-load periods. Because the losses are proportional to the square of the line loading, the decreasing in winding losses during the peak period tends to outweigh the increased losses during the off-peak period. Thus, in net, this leveling of load between on- and off-peak periods tends to reduce overall losses.

Since this use of storage is an ancillary benefit to transmission and distribution capacity deferral, the same issues surrounding price signals in restructured markets and incentivizing this use of storage in the vertically integrated paradigm apply here. It should be noted that the LMPs produced in most restructured wholesale markets include a “losses” component (in addition to the congestion charge). Thus, these LMPs provide the proper signal for DES to reduce losses on transmission lines. As noted before, no restructured market currently produces LMPs at the distribution level. Thus, there is currently no market-based incentive for this service and active utility involvement would currently be needed to incentivize this use of DES.

Phase Balancing

Tesla’s original design for poly phase electrical systems involved the future development of phase balancing technologies which were never completed or deployed. Phase balancing is an important factor in the efficient transmission and delivery of power but it is also a critical element for power quality. In distribution systems, it is relatively common to see an uncontrolled third phase or leg. Sometimes this is also described as the “wild” leg or phase. This is a symptom of a lack of phase balancing. DES systems are capable of providing real or reactive power by phase, meaning that DES is capable of providing different support to different phases. This capability allows DES to balance phases both in regards to load sharing as well as voltage regulation. This one capability may increase the power transfer at a substation by more than 30% because as substations get more and more loaded, phase balancing or lack thereof becomes more and more amplified. DES may be uniquely qualified to solve this important issue and phase balancing may be one of the most valuable benefits provided by DES.

Emergency Uses

Hurricanes Katrina and Sandy, among other storms, have shown the vulnerability of our electrical grid system. DES offers the possibility of supporting critical load segments even when the main grid is down. Also, DES can accelerate the restart of the grid system by testing and supporting the load circuits while the main grid is brought back to operation. DES can provide unique capabilities to resync a distribution system with the bulk system without significant load transfer and other synching issues, such as frequency and phase matching. The ability to test a distribution system without tying it to the bulk system is a major advantage of DES and also a major value even if it is difficult to access and quantify. Future distribution systems may have significant DER and those resources can best be utilized if DES is a core asset of the respective distribution system.

4. Public Policy and Market Practice Implications

As the transformation in the power sector unfolds, it is vital that regulatory policies at the state and federal level be aligned to recognize the value of storage by providing appropriate compensation and non-discriminatory access to the grid. Ideally, regulatory policies that advance market-based solutions would promote the greatest economic efficiency over the long-term and incorporate the fact that the latent intermittency of many resources poses a growing challenge to system operators, particularly at the distribution level so the deployment of storage technologies can be an effective solution for balancing power flows and voltage levels.

In order for this to happen, the owners of storage assets will require compensation for achieving a number of system benefits, such as:

- Energy reserves including system balancing by either discharging or absorbing energy.
- Capacity for meeting peak demand to the extent resources qualify as a capacity supply resource.
- Deferment of transmission and distribution investments.
- Reduction of customer outages.
- Ancillary services, including ones such as power quality and electricity customer energy management.

Due to the demarcation between transmission and distribution regulation (federal vs. state), federal and state regulators should consider instituting tariff-based or market-based compensation schemes that appropriately value the resource characteristics enumerated above.

Federal Level

At the federal level, FERC has made considerable progress in advancing policies that provide greater opportunity for storage resources to compete against conventional supply-side resources. In connection with capacity markets, FERC recently ordered a number of modifications to regional energy market designs in those areas where states have restructured to facilitate competitive markets. FERC's efforts now require that markets place considerable emphasis on the reliability characteristics of a resource—regardless of whether the resource is supply-side or demand-side. The predictability and dispatch ability of a resource, with particular emphasis on a resource's ability to meet the peak demand requirements of the system, are now key ingredients to the market design. These market rule changes should provide storage greater economic opportunity to compete against other resources in future capacity auctions.

A second effort by FERC relates to reserve markets. In Order 755, FERC ordered RTOs to modify the market design for frequency regulation services. The tariff revisions enhance the ability of limited-energy resources, such as storage, to participate in the frequency regulation market to the fullest extent possible. These changes will reduce the barrier to entry for storage resources. While these new policies are a step forward, more effort needs to focus on other RTO tariffs that allocate the cost of transmission across the region. A close examination of these tariffs is necessary to ensure that the allocation of transmission costs to load-serving entities (LSEs) accurately reflects the value of peak-load reduction, since those economic signals are critical to inform (and compensate) alternative technology resources, such as storage.

State Level

Equally important to the viability of storage is the development of good regulatory practices at the state level. The challenge can be broken down into two areas: compensation policies and interconnection policies. Similar to the recent efforts by FERC, states should also consider market-based or tariff structures that appropriately compensate storage resources for balancing system loads, maintaining adequate power quality, facilitating higher penetration of distributed renewable resources, reducing customer outages, and deferring the need for distribution capacity investments.

Similar to state policies that promote investment in DER, policies can be developed that facilitate utility-scale and/or behind-the-meter deployment of storage in those areas of the distribution system with high concentrations of DR, particularly where power flows are approaching or exceeding the capacity of the system. For small systems, the policies should facilitate aggregation of the resources by third parties since that would promote administrative efficiency in the coordination with distribution utilities and any tariff-based compensation programs. Aggregation also advances the feasibility of utilities bidding the resources in wholesale markets, similar to the way utilities achieve capacity market payments for demand-side and renewable resource investments. This incremental extraction of value will help to advance deployment of storage technologies.

Lastly, state regulators need to ensure that interconnection policies are fair and not unduly burdensome. Interconnection policies for storage should provide transparent procedures and criteria to customers and market participants, such as metering, site control, interconnection cost allocation, electric code consistency, and payment structures. Regarding payment structures, compensation can be in the form of a contract or tariff-based program, and should consider the option of bill credits (including net-negative metering). Technical assistance that will help states evaluate these policies is essential to the deployment of storage technologies, and DOE can play an important role in the development of best practices that could assist states in implementing regulatory mechanisms that will facilitate deployment of storage technologies in a manner that promotes economic efficiency and reliability.

5. Codes and Standards

As the demand and opportunity for DES grows, the development of codes and standards will be critical in ensuring; the development of a uniform language for product subcomponents, that fundamental materials are developed in a streamlined fashion so manufacturers can capitalize on economies of scale to decrease costs, and that different storage devices are interoperable with each other and the grid as a whole. Most importantly, codes and standards development will help ensure the safety of these products during their lifetime, subsequently encouraging consumer confidence and mass adoption. They will also ensure that responsible end-of-life plans are in place, and that interconnecting these devices with the greater bulk grid is as seamless as possible. These three components of codes and standards development—safety, disposal plans, and interconnection—are discussed in greater detail below.

Safety Considerations

Developing safety codes and standards is one of the most important areas in which the DOE can play a leading role. The Department's jurisdiction, convening power, and unbiased point of view, provide a unique opportunity for DOE to continue to facilitate this discussion. Future efforts should focus on closing the existing gaps in DES safety codes and standards that pertain to the fundamental components of these safety guidelines (validation techniques, incident response, and documentation), fire safety codes and standards, and site-specific codes and standards.

Key Components and Processes

DOE notes in its 2014 Energy Storage Safety Strategic Plan [16] that:

> *Safety of any new technology can be broadly viewed as having three intimately linked components: 1) a system must be engineered and validated to the highest*

[16] *US Department of Energy, Energy Storage Safety Strategic Plan, December 2014. http://energy.gov/sites/prod/files/2014/12/f19/OE%20Safety%20Strategic%20Plan%20December%202014.pdf*

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

This reasoning similarly applies to DES. Efforts have been made to develop protocols for storage performance evaluation, convene forums, and create CSR templates. While several of these efforts apply more broadly to energy storage at large, there are many overlapping lessons that can be applied to DES, and that can facilitate the codes and standards creation for it as well.

Still, work is needed in this area. Scientific testing of systems is needed to validate the safety of DES devices, with particular attention paid to the chemistries and "mechanistic responses" of each new storage system. Further, a streamlined process for researching, testing, and certifying the DES products that come to market—with transparent standards—must be solidified, especially as an increasing variety of devices are created and the industry becomes more crowded. A key component of this will be identifying the most likely areas for system failure when these devices are installed outside the testing environment, so that oversight can be applied and threats can be mitigated. Standards must then be implemented to ensure that the safest and most reliable devices and materials are promulgated, and that inherently risky devices are updated to reflect the safety codes.

In addition, standards must be put in place to quickly and efficiently handle any unplanned incidents that do occur. Events such as fires, either internally ignited or in the surrounding environment, are discussed below. Similarly, standardized documentation that is in a clear format and can be easily accessed by all relevant parties, is needed to consolidate the numerous efforts in standards development. This documentation must be routinely updated so that it is reliable and reflects the ongoing, evolving changes to safety codes and standards.

Fire Safety Codes and Standards

DES systems add an additional level of electrical complexity, and therefore potential hazard, to the homes, businesses, and commercial sites at which they are installed. Support is needed for testing and simulating the fire risk potential of these devices. These efforts should seek to identify which components, if any, pose the greatest fire hazards and how best to manage those risks. Subsequently, work is needed to determine the most effective response measures, keeping in mind that the typical fire response approaches and common suppressants may not interact as expected with the chemicals used in DES devices. These potential issue areas should be identified, tested, and translated into effective protocols before mass market penetration of DES.

Similarly, who responds, how responders are trained, how the incident is internally recorded, and what emergency plans are put into place must all be determined. Work is needed to identify the most effective fire mitigation efforts to preempt as many incidents as possible and ensure that damaged materials are repaired or disposed of properly to avoid residual incidents. This includes properly coding DES so that the appropriate "instantaneous" response mechanisms are put in place (e.g., the size and volume of on-site sprinklers), and ensuring that the best materials are used in the original design so that safety is engineered into the devices from the onset.

As the DOE Energy Storage Safety Strategic Plan[17] notes, fire suppression "is a very open area of research that needs quantitative findings in order to inform the industry." This remains true for DES. DOE can play an important role in this process by convening key stakeholders, facilitating discussions, and providing funding for testing and simulations.

Site-specific Codes and Standards

Attention must also be given to how the location of a DES system—for example inside a residential basement vs. outside at a commercial entity or business—affects the particular set of codes and standards to which the system is subjected. Work is needed to establish permitting and siting standards that are appropriate for the particular location, ownership type and size of the system. For systems that are co-located with generation facilities or in close proximity to sensitive areas (e.g., protected lands), consideration should be given to what additional permits or actions should be required. To facilitate greater adoption of DES, these permitting and siting processes should be established in a streamlined and user-friendly manner.

End-of-Life Considerations

When developing the set of codes and standards needed to ensure that DES systems are safe, reliable, and economically feasible, it is important to consider the entire life cycle of the product. This consideration should include the "end-of-life" stage: the disposal, recycling, and/or decommissioning options that are available for the device, as well as the advantages and disadvantages of each alternative. For example, several ISOs are now requiring end-of-life disposal costs and safety to be considered in their procurement requirements.

Testing is needed to determine the human safety risks associated with recommissioning or refurbishing DES products, as are standards for how to go about undertaking these tasks—if deemed viable. The reuse of even small components of DES devices pose an inherent risk to the engineers/operators who handle the product and the end-users who eventually receive the refurbished device. Thus, strict codes are needed that outline how these materials are handled and in what capacity they can be reintroduced to the market.

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[17] *US Department of Energy, Energy Storage Safety Strategic Plan, December 2014. http://energy.gov/sites/prod/files/2014/12/f19/OE%20Safety%20Strategic%20Plan%20December%202014.pdf*

The process of establishing standards for recycling/reusing versus disposing of/decommissioning DES products should take into account the environmental impacts of each option. For example, there is a need for determining—through testing, environmental impact assessments, or other relevant approaches—what the proper disposal techniques are for the chemical components and other potentially hazardous materials used in DES devices. These processes must then be incorporated into the relevant codes and guidelines.

Interconnection

Effectively incorporating a growing number of DES systems onto the grid requires a systematic, transparent approach with clearly defined codes and standards. Coordinating and developing the technical aspect of these processes is a critical part of ensuring that interconnection is feasible, non-discriminatory, safe, and cost-effective.

There are several ongoing efforts in this area. The well-known IEEE 1547 family of Standards for Interconnecting Distributed Resources with Electric Power Systems and its subsequent updates were extremely beneficial in providing a basis for shared practices. The recent IEEE 1547A-2014[18] update (which is still in the process of dissemination and adoption) allows DER to assist with voltage and frequency regulation (with System Operator approval). California's Electric Rule 21[19]—an evolving rule that has looked to 1547A for guidance and which describes the interconnection, operating, and metering requirements for generation facilities to be connected to a utility's distribution system—incorporates (or will incorporate, given that it is an evolving rule) multiple functions. These include high/low voltage ride-through and high/low frequency ride-through, volt-VAR control, and soft-start reconnections by ramping or randomly within a time window (default window of 15 seconds). These can serve as useful examples of the types of functions to incorporate when designing more robust, far-reaching codes and standards.

Still, significant work is needed to fill the gaps in DES-relevant interconnection codes and standards development. A complete revision of IEEE 1547,[20] which was proposed in 2013 and targeted for completion by 2018, would further serve to establish standardized procedures. Opportunities also exist to standardize and improve systems communications protocols, frequency smoothing, automatic generation control, advanced inverter functions, and a host of other functions. DOE can help convene key stakeholders and play a neutral mediator role in these discussions.

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[18] *Sandia National Laboratories, March 2015. http://www.apec-conf.org/wp-content/uploads/Neely_Alt_Energy_APEC_2015_Talk_Final.pdf*
[19] *California Public Utility Commission, July 2015. http://www.cpuc.ca.gov/PUC/energy/rule21.htm*
[20] *IEEE, February 2015. http://grouper.ieee.org/groups/scc21/1547_revision/1547revision_index.html*

Appendix A: Distributed Energy Resources (DER): Distributed Storage Behind-the-Meter

Behind the meter devices are quickly becoming a major player in electricity markets and grid operations. Distributed Energy Resources (DER) include both resources that aggregators offer into markets through Demand Response programs (that change net demand associated with flexible demand, distributed generation) and distributed energy storage that responds to anticipated prices and is not specifically offered into the market. In organized power markets, Demand Response programs play a large role in capacity and some ancillary service and energy markets.[21] Changes in net customer demand outside of such programs can be expected to play an increasing role in avoiding capacity obligations and reduce energy costs. This Appendix is included to provide an overview of DER and to provide a basis for future study consideration by this Electricity Advisory Committee.

Flexible Demand

Flexible demand (FD) that shifts the timing of electricity demand in response to anticipated prices is a large and cost-effective form of virtual storage. Smart devices, such as smart thermostats and building automation systems, can take advantage of thermal inertia in heating and cooling buildings, heating water, and refrigeration. It can capitalize on flexibility in the timing of power use for pumping loads, batch processes, dishwashers, charging electric vehicles, and other devices. This flexibility represents a large untapped and inexpensive source of energy storage.

For example, smart residential thermostats that shift demand to take advantage of a home's thermal inertia can provide significant amounts of virtual energy storage. By signaling such thermostats to pre-cool homes before a peak in air conditioning demand, utilities have achieved as much as a 3kW per household or 50% reductions in residential air conditioning demand in peak periods.[22] Grid-interactive storage water heaters have similar benefits, shifting demand to lower cost periods, reducing wholesale power costs, helping integrate renewable generation, and providing ancillary services to grid operators.[23] Overall, smart devices could shift a significant portion of residential electricity demand to lower price periods. A California study estimated the thermal inertia of residential air conditioning given

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[21] Federal Energy Regulatory Commission, *Assessment of Advanced Metering and Demand Response Staff Report* (December 2014).

[22] Application of Nevada Power Company d/b/a NV Energy for Approval of its 2014 Annual Demand Side Management Update Report as it relates to the Action Plan of its 2013-2032 Triennial Integrated Resource Plan, Volume 5 – Technical Appendix, available at: http://pucweb1.state.nv.us/PUC2/DktDetail.aspx. See also: Tom Kerber, *Residential Savings through Data Analytics* (Downloaded June 10, 2014 from: http://www.ecofactor.com/resources/, and M. Kanellos, *EcoFactor Says It Beasts Nest in Home Energy Management* (Downloaded at: http://www.forbes.com/sites/michaelkanellos/2014/08/27/ecofactor-says-it-beats-nest-in-home-energy-management/ August 27, 2014). Nest, *The Results Are In: Nest Announces Energy Services Savings* (May 15, 2014). See also: *Inside Nest* (Downloaded June 10, 2014 from: https://nest.com/blog/2013/07/18/our-first-rush-hour-rewardsresults/).

[23] Paul Steffes, *Grid Interactive Electric Thermal Storage Water Heating* (2012). See also: R. Farrell Troutfetter, *Market Potential Study for Residential Water Heater Demand Management* (March 5, 2010) which estimates that 5,300 MW demand reduction could be achieved without any direct effect on customer comfort given controls on 25 percent of electric water heaters.

no more than 1°C of temperature flexibility, water heaters with up to 4°C of flexibility, and refrigerators with up to 2°C of flexibility could permit smart devices to shift 20 GW or more of the state's residential demand during more than 2,000 hours of the year and provide at least 8 to 11 GWh of energy storage throughout the year. This estimate suggests that during much of the year smart devices have the potential to shift a majority of California's residential electricity demand to different intervals. For a California residential customer, shifting electricity demand to lower cost intervals could reduce their estimated energy costs for air conditioning (at wholesale market prices) by about 10% and their energy costs for water heating and refrigeration by up to 40% or more.[24] In a similar case study on flexible demand, Rocky Mountain Institute concluded that intelligent management of residential air conditioning, water heating, and EV charging could provide as much as $250 per year in net savings to residential consumers in Chicago without impacting service quality.[25]

Large commercial buildings typically have greater thermal inertia than homes and a growing number of commercial customers are using building automation systems to shift demand and reduce energy costs. A review of seven years of experience with automated demand response at 250 commercial and industrial facilities found that commercial buildings reduced their peak demand by an average of 13 percent and that industrial facilities achieved greater demand reductions.[26] Some commercial and industrial customers have used automated controls to reduce their demand in peak periods by more than 25 percent.[27]

A 2011 National Energy Technology Laboratory study identified the potential for smart energy using devices to shift the timing of energy usage, reduce peak demand by more than 25%, and produce billions of dollars per year in economic, reliability, and environmental benefits.[28]

It is important to note that flexible demand does not require the use of time varying retail rates. A competitive retail supplier or utility can offer customers a lower fixed price in return for the customer having a smart thermostat or smart devices that automatically shift a portion of demand to lower cost periods.

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[24] J. Mathieu, *Modeling, Analysis, and Control of Demand Response Resources,* LBNL-5544E (May 2012); J. Mathieu, et al., "Using Residential Electric Loads for Fast Demand Response: The Potential Resource and Revenues, the Costs, and Policy Recommendations, *Proceedings of the 2012 ACEEE Summer Study on Energy Efficiency in Buildings* (August 2012). Estimates were based on estimated device saturations in 2020. As a point of comparison, the contemporaneously prepared forecast for 2020 of residential non-coincident peak demand was 29,105 GW and of residential average hourly electricity consumption was 11,959 GWh. California Energy Commission Staff, *2012 -2022 Final Forecast, Volume 1* (May 2012).

[25] Rocky Mountain Institute, The Economics of Demand Flexibility: How "Flexiwatts" Create Quantifiable Value for Customers and the Grid (August 2015).

[26] S. Kiliccote, "Findings from Seven Years of Field Performance from Automated Demand Response in Commercial Buildings," *Proceedings of the 2010 ACEEE Summer Study on Energy Efficiency in Commercial Buildings* (August 2010).

[27] Vermont Transco, LLC, *Automated Demand Response Benefits California Utilities and Commercial & Industrial Customers,* Prepared for the U.S. Department of Energy (September 2014).

[28] J. Goellner, et. al, *Demand Dispatch – Intelligent Demand for a More Efficient Grid,* National Energy Technology Laboratory (August 2011).

Given its potential, flexible demand could be one of the greatest untapped forms of energy storage on the grid. The EAC is undertaking other work to examine the energy impacts of connected devices, the Internet of Things.

Thermal Storage

Thermal Storage is one of the oldest of the DES technologies that dates back to the Roman Era. The ability to be able to store thermal energy for use in a later timeframe is not a new idea but the impact of thermal storage in DES and DER space could be very large. Recently, thermal storage has been used to either pre-cool facilities or make ice at night for use during the day to offset AC loads. The same is true for the reverse: storing heat during the day for use at night. Some recent reports show that pre-cooling or pre-heating of large facilities could represent several GWhrs of storage just for the State of California. The storage media have improved over time. Key considerations are the cost and efficiency of the storage media as compared to the cost of the electrical power used and that which is offset.

Electric Vehicles

The emerging EV and PHEV markets have led to a renewed interest in using the vehicles' battery systems as key elements of DES. Most of the OEMs have conducted laboratory and field trials related to the expanded use of the vehicles' charging and battery systems with an advanced DES control system. To date, these tests have shown the technical feasibility of this approach. However, using a vehicle's battery for DES appears to increase the product liability that the OEMs would have to cover. Also, bi-directional chargers and bi-directional interconnects significantly increase the cost of the fully installed system. Beyond these issues, the OEMs and DER aggregators have been conducting tests that vary the charging of the EV and PHEV batteries to provide a controllable load that could be used for grid balancing or the provision of ancillary services. So far, the field and market tests using this approach appear to be very favorable.

Compressed Air

Technology advancements in compressed air storage in specially designed tanks and adiabatic processes for compressing and releasing compressed air have made this option more attractive. Typically limited to industrial settings due to the size and complexity of this type of energy storage, technology advancements may make this technology available for commercial applications as well. Further advancements are needed to make this option more attractive for energy storage at smaller scales.

Hydrogen

The basic idea is to generate hydrogen during off-peak hours and use that hydrogen to offset peak power requirements. Similar to compressed air, this option is typically deployed in an industrial setting but major commercial facilities are considering this option as well. Also similar to compressed air, the installation and operating costs are challenging and require significant demand charges and low off-peak power costs to justify the installation costs. Some experts[29] believe that hydrogen is the best energy cycle for the future.

Regulatory Challenges

Traditionally, system operators of the bulk power grid have focused on managing different sources of supply and have treated the load as an exogenous input. The daily pattern of load on a distribution network is predictable, and the operating criterion in a typical security-constrained optimal power flow (SCOPF) is to minimize the cost of supplying these predicted loads and cover a specified set of equipment failures (contingencies). Treating load as an exogenous input for planning expansion of the grid has resulted in a situation in which the peak system load grew faster than the annual demand for electric energy. Consequently, some generating units have very low capacity factors and, given price ceilings in wholesale energy markets, do not earn enough revenue in the energy market to justify their capital costs. As a result, capacity markets have been established in some regions to provide an additional source of revenue to cover this "missing" money.

Technically, it would be perfectly feasible to meet the objectives of climate change policy and continue with the established supply-side focus of the electric utility industry. For example, dedicated storage capacity could be installed to mitigate the variability of generation from renewable sources. However, dedicated supply resources are relatively expensive because their full cost has to be justified by lowering the total cost of supply. In this respect, many DER have a distinct financial advantage because their high capital cost is shared with the provision of another energy service to customers. This is the case for the batteries in electric vehicles, for controls used in HVAC space conditioning, and for electric storage water heaters. These are all potentially large sources of virtual energy storage.

Managing demand to support the electric delivery system is an important capability that is currently underutilized. Smart devices and other forms of DER can still provide customers with energy services (e.g., transportation, space conditioning, and hot water) when they want them and, at the same time, reduce the overall cost of supplying electricity and still maintain the reliability of the grid. These capabilities will also have important effects on the performance of wholesale markets for electricity by flattening daily load cycles, responding to operating events on the power grid, and reducing the peak system load. Since the capacity of the electric delivery system is designed to meet the peak system load, reducing this peak and the associated capital cost of equipment (e.g., peaking units with low capacity factors) is an important way to reduce the total system costs and the amount of congestion on the grid. In contrast, the peak system load is not reduced when only supply-side solutions to problems are considered. Although utility-scale storage can mitigate the variability of generation from renewable sources and flatten the daily pattern of generation for conventional generating units, the overall

[29] *Engadget. 2014. Toyota's first hydrogen car is priced to go head-to-head with Tesla. Accessed via http://www.engadget.com/2014/06/25/toyota-hydrogen-fuel-cell-car-vs-tesla/*

capacity of supply must still be large enough to meet the peak system load. Energy from storage simply substitutes for some conventional generation for a given peak load.

It is encouraging that there is now an increasing recognition by regulators that demand response and DER are effective but underutilized ways of improving the performance of electricity markets and lowering costs to customers. For example, the State of New York Public Service Commission (NYPSC) issued an order (CASE 07-M-0548 – Proceeding on Motion of the Commission Regarding an Energy Efficiency Portfolio: Order Issued and Effective December 26, 2013)[30], which included the following statement:

> *"The Commission and other policy makers can no longer afford to think of energy efficiency and distributed clean energy resources as peripheral elements of the electric system that require continuous government support. Rather, the time has come to manage the capabilities of these customer based technologies as a core source of value to electric customers. In addition, full integration of load management capabilities into energy supply and grid management decisions will improve system wide reliability, efficiency, and resiliency at just and reasonable rates for New Yorkers."*

This initiative was endorsed by Governor Cuomo in April, 2014[31] who issued a press release to announce the Reforming Energy Vision initiative that included the following statement about peak demand:

> *"The best example of the value of modernizing the electric grid is the current inefficiency of peak demand. Peak demand for electricity happens on the hottest days of the summer when electricity demand skyrockets, but only temporarily. While it is understandable and prudent to ensure that demand for energy can be met at all times, it is also inefficient and costly. As a result, consumers are now forced to spend hundreds of millions annually to maintain the full capabilities of a system that is needed only on the very hottest days of the summer."*

Overall, the expectation of the Reforming Energy Vision is that *"utilities will actively manage and coordinate a wide range of distributed resources, or generate electricity from many small energy sources and link them together"* (Cuomo 2014).

If a system operator manages FD devices efficiently, particularly for space cooling in summer-peaking regions, the main savings in the operating cost of supplying electricity come from 1) shifting load from peak to off-peak periods and reducing the peak system load, and 2) by providing ramping services to

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[30] New York State Public Service Commission, Proceeding on Motion of the Commission Regarding and Energy Efficiency Portfolio Standard, Issued and Effective December 26, 2013. Available at: http://documents.dps.ny.gov/public/Common/ViewDoc.aspx?DocRefId={7705D91D-ACB8-4560-9984-

[31] New York State Department of Public Service. Proceeding on Motion of the Commission in Regard to Reforming the Energy Vision, 2014. Available at: http://www3.dps.ny.gov/W/PSCWeb.nsf/96f0fec0b45a3c6485257688006a701a/26be8a93967e604785257cc40066b91a/%24FILE/ATTK0J3L.pdf/Reforming%20The%20Energy%20Vision%20(REV)%20REPORT%204.25.%2014.pdf

accommodate the variability of generation from renewable sources and reducing the amount of conventional generating capacity needed for operating reserves. FD devices can also lower the costs for individual customers if the rate structures that either include a dynamic rate or a discounted flat price reflect the true cost of supplying them.

One of the fundamental concepts underlying competitive markets is that if participants provide services that increase social welfare, they should be compensated, and if they receive services that others provide by incurring some cost, they should pay for those services. This basic economic rule should apply to electricity markets if they are to provide the correct economic incentives for encouraging investment in FD. Ideally, all customers, or the competitive retail suppliers or aggregators representing them, should be able to 1) benefit from price arbitrage under real-time pricing, 2) pay lower demand charges if they reduce their purchases during peak load periods, and 3) receive compensation for providing ramping services. Modifying existing wholesale settlement practices or retail rate structures to reflect efficient usage patterns is a major challenge facing regulators, but these modifications are essential for developing an efficient two-sided market for electricity with full participation by DER.

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