New York Battery and Energy Storage Technology Consortium, Inc.

February 6, 2014

The New York Independent Systems Operator
Attention: Ms. Debbie Eckels
10 Krey Boulevard
Rensselaer, New York 12144

NY-BEST Comments on
NYISO Distributed Energy Resources Workshop on December 13, 2013

Dear Ms. Eckels:

Please accept these comments on the NYISO Distributed Energy Resources Workshop on December 13, 2013, on behalf of the New York Battery and Energy Storage Technology Consortium (NY-BEST).

NY-BEST was pleased to participate in the NYISO Distributed Energy Resources workshop on December 13, 2013 and we greatly appreciate the opportunity to provide additional comments. The workshop offered valuable dialogue and information on the role distributed energy resources can play in strengthening our electric grid.

The New York Battery and Energy Storage Technology Consortium (NY-BEST™) is a rapidly growing, industry-led, private-public coalition of corporate, entrepreneurial, academic, and government partners building a vibrant, world-class advanced battery and energy storage sector, from R&D to commercialization, in New York State. Our diverse members include Fortune 500 companies, start-ups, universities, national research centers and laboratories spanning all facets of the energy sector.

NY-BEST member companies are involved in developing energy storage technologies for both on-grid and behind-the-meter applications. They also represent different energy storage technologies from thermal and mechanical storage, to fuel cells and multiple types of battery and capacitor technologies. As such, NY-BEST and our members can serve as a resource to

NYISO as this study progresses and we encourage you and your team to utilize us and our deep bank of expertise to augment your work.

As we discussed at the workshop, energy storage technologies are an essential part of our efforts to modernize the electric grid. Energy storage technologies can relieve grid congestion, reduce greenhouse gas and other harmful air emissions, increase efficiency, enable the wide-scale deployment of intermittent renewable energy sources, and improve the electric system's reliability and resiliency.

In support of these comments, we would like to draw your attention to the US Department of Energy's "Grid Energy Storage Report" released on December 2013. (Report is attached hereto for your reference.)

The following excerpt from page 20 of the DOE Report highlights the areas where storage can be particularly beneficial:

> *"The 2013 edition of the DOE/EPRI Electricity Storage Handbook describes eighteen services and applications in five umbrella groups, as listed in Table 4. The services and applications identified in this table show that energy storage can be used to support generation, transmission, and distribution, as well as customer-side-of-the-meter needs of the grid. This section describes some of the functions most commercially viable and relevant to the near-term future of the grid.*

Table 4 – Electric Grid Energy Storage Services

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

Recognizing energy storage can have multiple services within the grid allows it to capture multiple benefit streams to offset system costs. The flexibility of storage can be leveraged to provide multiple or stacked services, or use cases, with a single storage system that captures several revenue streams to achieve economic viability. How these services are stacked depends on the location of the system within the grid and the storage technology used. However, due to regulatory and operating constraints, stacking services is a process that requires careful planning and should be considered on a case-by-case basis."

The DOE Report also includes additional information that responds directly to your request for information on applicable current and near-term technologies, and possible and current applications for grid or customer benefit.

In New York, energy storage is of particular interest with respect to capacity, resiliency, and renewable integration. As part of the Indian Point Closure Contingency plan, Consolidated Edison and NYSERDA recently announced a set of incentives for summer on-peak demand reduction that include specific incentives to support the installation and operation of battery and thermal storage systems. We encourage you to review these incentives as part of your study and work going forward.

DNV GL recently completed a study for NYSERDA analyzing the resiliency benefits of incorporating energy storage with PV systems. In addition to resiliency, energy storage can smooth output, time shift output, and avoid backfeeding. (See attached Power Point for additional details.)

Again, we thank you for the opportunity to participate in the workshop and provide these comments. NY-BEST stands ready to assist you on this important study.

Sincerely,

Dr. William Acker
Executive Director, NY-BEST

Attachments

Grid Energy Storage

U.S. Department of Energy

December 2013

Acknowledgements

We would like to acknowledge the members of the core team dedicated to developing this report on grid energy storage: Imre Gyuk (OE), Mark Johnson (ARPA-E), John Vetrano (Office of Science), Kevin Lynn (EERE), William Parks (OE), Rachna Handa (OE), Landis Kannberg (PNNL), Sean Hearne & Karen Waldrip (SNL), Ralph Braccio (Booz Allen Hamilton).

Table of Contents

Table of Figures and Tables

Executive Summary

Modernizing the electric system will help the nation meet the challenge of handling projected energy needs—including addressing climate change by integrating more energy from renewable sources and enhancing efficiency from non-renewable energy processes. Advances to the electric grid must maintain a robust and resilient electricity delivery system, and energy storage can play a significant role in meeting these challenges by improving the operating capabilities of the grid, lowering cost and ensuring high reliability, as well as deferring and reducing infrastructure investments. Finally, energy storage can be instrumental for emergency preparedness because of its ability to provide backup power as well as grid stabilization services.

At present, the U.S. has about 24.6GW (approx. 2.3% of total electric production capacity) of grid storage, 95% of which is pumped storage hydro.[1] Europe and Japan have notably higher fractions of grid storage. Pursuit of a clean energy future is motivating significantly increased storage development efforts in Europe and Asia, as well as the U.S.

Energy storage technologies—such as pumped hydro, compressed air energy storage, various types of batteries, flywheels, electrochemical capacitors, etc., provide for multiple applications: energy management, backup power, load leveling, frequency regulation, voltage support, and grid stabilization. Importantly, not every type of storage is suitable for every type of application, motivating the need for a portfolio strategy for energy storage technology.

There are four *challenges* related to the widespread deployment of energy storage: cost competitive energy storage technologies (including manufacturing and grid integration), validated reliability & safety, equitable regulatory environment, and industry acceptance. Issues that are being explored in this paper focus on reducing system costs through targeted application of science and engineering research and development for new storage concepts, materials, components and systems (including manufacturability and standardization). Developers should consider technical risk mitigation, for controlling the uncertainties at the early stage of deployment so that cost estimates and operational practices can develop based upon well-grounded and fully understood data. Ongoing research and development, from fundamental science of energy storage mechanisms to

[1] http://www.energystorageexchange.org/ (All data cited in this paragraph is current as of August 2013). Note that the database has only verified the details of 121 of these deployments, with the details on the remaining projects in various stages of verification.

the early stage development of platform technologies should also be considered in support of these challenges. Industrial standards for grid storage are in their infancy. Industry acceptance could also gain ground when we reduce the uncertainty surrounding how storage technology is used, and monetized, at scale. Ultimately, it will be the experience and real-world use of storage that will provide the confidence and desire to expand installed storage.

The expansion of the electricity system can be accelerated by the widespread deployment of energy storage, since storage can be a critical component of grid stability and resiliency. ***The future for energy storage in the U.S. should address the following issues: energy storage technologies should be cost competitive (unsubsidized) with other technologies providing similar services; energy storage should be recognized for its value in providing multiple benefits simultaneously; and ultimately, storage technology should seamlessly integrate with existing systems and sub-systems leading to its ubiquitous deployment***.

In reviewing the barriers and challenges, and the future for energy storage, a strategy that would address these issues should comprise three broad outcome-oriented goals:

1. Energy storage should be a broadly deployable asset for enhancing renewable penetration – specifically to enable storage deployment at high levels of new renewable generation
2. Energy storage should be available to industry and regulators as an effective option to resolve issues of grid resiliency and reliability
3. Energy storage should be a well-accepted contributor to realization of smart-grid benefits – specifically enabling confident deployment of electric transportation and optimal utilization of demand-side assets.

To realize these outcomes, the principal challenges to focus on are:

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

- **Industry acceptance –** Industry adoption requires that they have confidence storage will deploy as expected, and deliver as predicted and promised.

DOE is addressing these challenges in the following ways:

Challenge/Goal	Strategy Summary
Cost competitive energy storage technology	• Targeted scientific investigation of fundamental materials, transport processes, and phenomena enabling discovery of new or enhanced storage technologies with increased performance • Materials and systems engineering research to resolve key technology cost and performance challenges of known and emerging storage technologies (including manufacturing) • Seeded technology innovation of new storage concepts • Development of storage technology cost models to guide R&D and assist innovators • Resolution of grid benefits of energy storage to guide technology development and facilitate market penetration
Validated reliability and safety	• R&D programs focused on degradation and failure mechanisms and their mitigation, and accelerated life testing • Development of standard testing protocols and independent testing of prototypic storage devices under accepted utility use cases • Track, document, and make available performance of installed storage systems
Equitable Regulatory Environment	• Collaborative public-private sector characterization and evaluation of grid benefits of storage • Exploration of technology-neutral mechanisms for monetizing grid services provided by storage • Development of industry and regulatory agency-accepted standards for siting, grid integration, procurement, and performance evaluation
Industry acceptance	• Collaborative, co-funded field trials and demonstrations enabling accumulation of experience and evaluation of performance – especially for facilitating renewable integration and enhanced grid resilience • Adaptation of industry-accepted planning and operational tools to accommodate energy storage • Development of storage system design tools for multiple grid services

1.0 Introduction

Modernizing the electric grid will help the nation meet the challenge of handling projected energy needs—including addressing climate change by relying on more energy from renewable sources—in the coming decades, while maintaining a robust and resilient electricity delivery system. By some estimates, the United States will need somewhere between 4 and 5 tera kilowatt-hours of electricity annually by 2050.[2] Those planning and implementing grid expansion to meet this increased electric load face growing challenges in balancing economic and commercial viability, resiliency, cyber-security, and impacts to carbon emissions and environmental sustainability. Energy storage systems (ESS) will play a significant role in meeting these challenges by improving the operating capabilities of the grid as well as mitigating infrastructure investments. ESS can address issues with the timing, transmission, and dispatch of electricity, while also regulating the quality and reliability of the power generated by traditional and variable sources of power. ESS can also contribute to emergency preparedness. Modernizing the grid will require a substantial deployment of energy storage. In the past few years, the urgency of energy storage requirements has become a greater, more pressing issue that is expected to continue growing over the next decade:

- California enacted a law in October 2010 ***requiring*** the California Public Utilities Commission (CPUC) to establish appropriate 2015 and 2020 ***energy storage procurement targets for California load serving entities, if cost effective and commercially viable by October 2013*** (AB 2514). In February 2013, the CPUC determined that Southern California Edison must procure 50 MW of energy storage capacity by 2021 in Los Angeles area. Additionally, in June 2013, the CPUC proposed storage procurement targets and mechanisms totaling 1,325 MW of storage. Other States are looking to the example that California is setting, and Congress has introduced two bills that establish incentives for storage deployment.[3]
- The increasing penetration of renewable energy on the grid ***to meet renewable portfolio standards*** (RPS) may be linked with greater deployment of energy storage. Storage can "smooth" the delivery of power generated from wind and solar technologies, in effect, increasing the value of renewable power. Additionally, when energy storage is used with ***distributed generation***, it can improve the reliability of those assets by providing power-conditioning value, and enables increased renewable penetration to help contribute to meeting state RPS.

[2] For a table of several such estimates, see Hostick, D.; Belzer, D.B.; Hadley, S.W.; Markel, T.; Marnay, C.; Kintner-Meyer, M. (2012). End-Use Electricity Demand. Vol. 3 of Renewable Electricity Futures Study. NREL/TP-6A20-52409-3. Golden, CO: National Renewable Energy Laboratory.

[3] The bills before congress are S. 1030 (STORAGE Act) and S. 795 (MLP Parity Act). Details on the California bill (AB 2514) can be found on the CPUC website: http://www.cpuc.ca.gov/PUC/energy/electric/storage.htm

- Energy storage is already near commercial viability in augmenting power management and frequency regulation techniques. Large flywheel installations and power monitoring software have combined to make flywheel installation useful in ensuring that intermittent sources and variable load demands maintain a 60 Hz frequency, storage could be an alternative method of providing spinning reserve or curtailment which could ***improve the efficiency of infrastructure and reduce greenhouse gas emissions*** caused by wasteful excess capacity and lowered heat-rates associated with excessive plant cycling.
- Energy storage can reduce the need for major new transmission grid construction upgrades as well as ***augment the performance of existing transmission and distribution assets.*** DOE estimates that 70% of transmission lines are 25 years or older, 70% of power transformers are 25 years or older, and 60% of circuit breakers are more than 30 years old.[4] Extending the capability of the transmission grid—for example by pre-positioning storage on the load side of transmission constraint points—makes the grid more secure, reliable, and responsive. Additionally, distributed storage can reduce line-congestion and line-loss by moving electricity at off-peak times, reducing the need for overall generation during peak times. By reducing peak loading (and overloading) of transmission and distribution lines, storage can extend the life of existing infrastructure.
- Moreover, as the nation moves towards the ***electrification of the transportation sector***, energy storage for vehicles, and the integration of energy between vehicles and the grid, will be critical. The focus on storage is not only for the deployment of batteries in vehicles, but also for potential second-life applications for electric vehicle (EV) batteries. For example, Project Plug-IN, a large scale public/private EV initiative based in Indianapolis, involving Duke Energy, is exploring the best customer use for stationary applications in homes, neighborhoods, and commercial buildings. This pilot project is being used to help validate the business models for future commercialization of storage technologies.
- Energy storage will also play a significant role in emergency preparedness and increasing overall grid resilience. An August 2013 White House report,[5] written in conjunction with the Office of Electricity Delivery & Energy Reliability, details the integral role that energy storage will play in enhancing grid resilience and robustness related to weather outages and other potential disruptions.[6]

[4] Fitch Ratings, "Frayed Wires: US Transmission System Shows Its Age," 2006
[5] "Economic Benefits Of Increasing Electric Grid Resilience To Weather Outages" August 12, 2013. Available at: http://energy.gov/sites/prod/files/2013/08/f2/Grid%20Resiliency%20Report_FINAL.pdf
[6] See also "Storm Reconstruction: Rebuild Smart: Reduce Outages, Save Lives, and Protect Property," NEMA, National Electrical Manufacturers Association, 2013; and " Recommendations to Improve the Strength and Resilience of the Empire State's Infrastructure," NYS 2100 Commission, 2012.

- Energy storage is poised to grow dramatically, requiring large investment in manufacturing capacity and jobs. According to an Information Handling Services, Cambridge Energy Research Associates (IHS CERA) report, ***the energy storage business could grow from $200 million in 2012 to a $19 billion industry by 2017***.[7]

The Department of Energy serves a vital role in resolving major challenges that are hampering widespread deployment of grid energy storage. Teaming with industry, State and municipal governments, academia, and other Federal agencies, DOE supports the discovery of new technologies to improve cost and performance of grid energy storage, spur technology innovation and incorporation into improved storage products, remove unnecessary barriers to deployment, and facilitate the establishment of industry-wide standards to ease widespread adoption of storage. These activities can help to ***catalyze the timely, material, and efficient transformation of the nation's energy system and secure U.S. leadership in clean energy technologies.*** DOE's 2011 Strategic Plan has identified a number of targeted outcomes in support of this goal, the most relevant to this mission includes reducing energy storage costs 30% by 2015 and supporting the integration of Plug-in Hybrid Electric and Battery Electric Vehicles as they shift load profiles[8].

Storage technology can help contribute to overall system reliability as large quantities of wind, solar, and other renewable energy sources continue to be added to the nation's generation assets, furthering the goals of reducing greenhouse gas emissions and increasing energy security. Additionally, storage technology will be an instrumental tool in managing grid reliability and resiliency by regulating variable generation and improving microgrid and smart-grid functionality. For micro- and smart-grid technologies, storage can provide redundancy options in areas with limited transmission capacity, transmission disruptions, or volatile demand and supply profiles.

The Department's electric energy storage program can create economic opportunities, as well. A strong storage market will foster a robust manufacturing base of advanced electric energy storage devices in the U.S., and this capability can be leveraged for export opportunities in the robust foreign market for storage. Further, by enabling more efficient adoption of renewable energy sources in the US, storage can help promote US energy independence and reduce carbon emissions.

Overview of this Report –This report sets out potential options to improve energy storage. It also presents a number of specific actions that could help maintain both

[7] IMS Research (now owned by IHS-CERA) report 'The Role of Energy Storage in the PV Industry – World – 2013 Edition'.
[8] U.S. Department of Energy 'Strategic Plan May 2011' (http://energy.gov/sites/prod/files/2011_DOE_Strategic_Plan_.pdf) page 15 and page 17

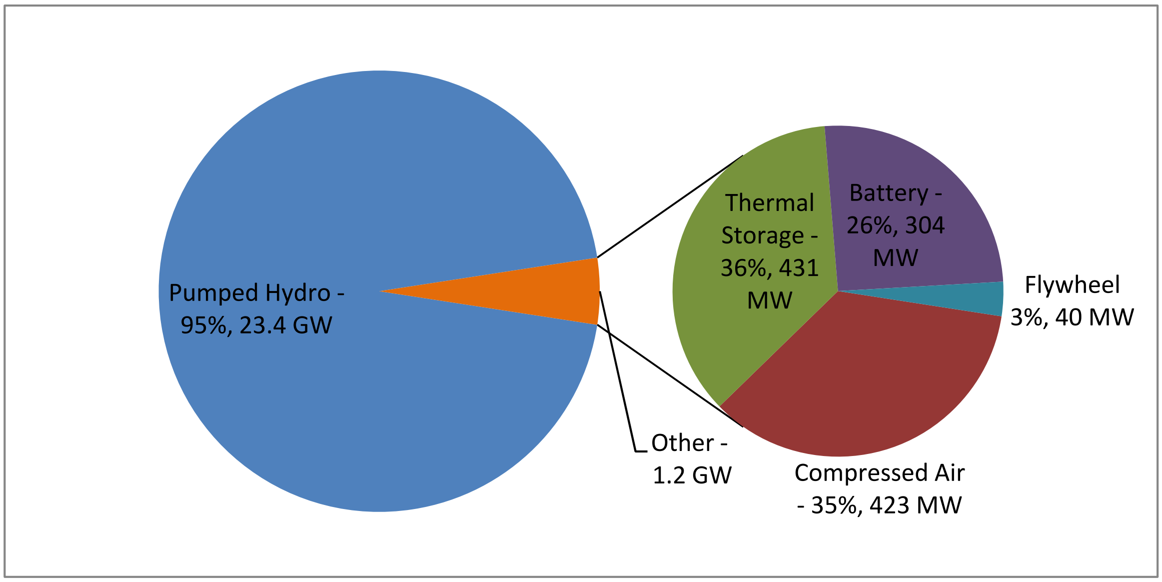
scientific advancements and a pipeline of project deployments. *This report does not address new policy actions, nor does it specify budgets and resources for future activities.*

Section 2.0 of this report describes the present state of energy storage in the US, as well as international projects that could serve as a near-term template for US investment and growth. Section 3.0 describes the present state of technology for energy storage, including the applications and opportunities for each technology type. Section 4.0 discusses the barriers and challenges to widespread adoption of grid-storage techniques, as well as other concerns that will need to be addressed. Sections 5.0 and 6.0 highlight ideas on how to promote and advance energy storage over the next three to five years, ranging from promoting basic research to promoting and analyzing present and future grid-storage markets. Section 7.0 discusses goals related to technology developments while section 8.0 discusses goals related to analysis. Finally section 9.0 addresses standardization and DOE's ongoing activities. The appendices detail storage R&D programs at relevant DOE offices and several Federal agencies and provides a listing of American Recovery and Reinvestment Act of 2009 (ARRA) funded energy storage projects.

2.0 State of Energy Storage in US and Abroad

An interactive database[9] created and maintained by DOE provides a snapshot of the extent and range of energy storage systems deployments worldwide. As of August 2013, the database reported 202 storage system deployments in the US with a cumulative operational capability of 24.6 GW, with a mix of storage technologies including pumped hydro, various types of batteries, and flywheels.[10] The contribution of each technology to the overall operational capability is shown in Figure 1. At 95%, pumped hydro clearly dominates due to its larger unit sizes and longer history as the technology of choice for energy storage by the electric utility sector. Other technologies such as compressed air energy storage (CAES), thermal energy storage, batteries, and flywheels constitute the remaining 5% of overall storage capability.

Figure 1 – Rated Power of US Grid Storage projects (includes announced projects)

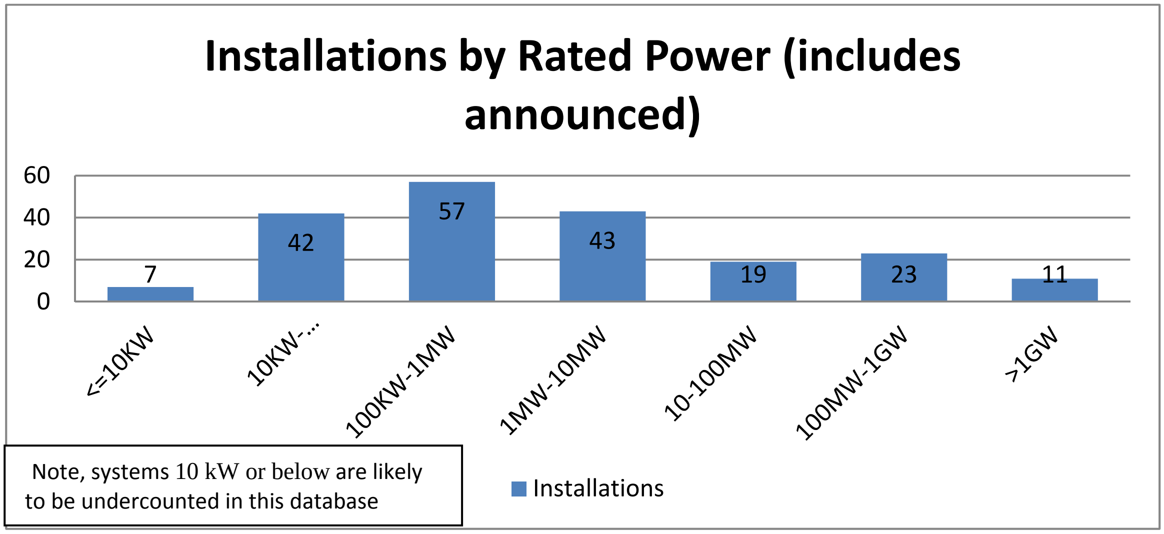


Similarly, Figure 2 shows the wide range of system sizes that have been deployed. The rated power of the various projects ranges from small, residential scale (7 projects are listed as 10 kW or below—this is a reporting artifact, as there are likely many small systems not in the database) to large, utility scale systems of 1 MW or more.[11]

Figure 2 – Number of US installations, grouped by capacity

---

[9] : http://www.energystorageexchange.org/ (All data cited in this paragraph is current as of August 2013)
[10] Note that the database has only verified the details of 121 of these deployments, with the details on the remaining projects in various stages of verification.
[11] This information also was accessed in August 2013, and can be found at: http://www.energystorageexchange.org/



Energy storage systems and the services they provide can be used in regulated and deregulated markets. However, for energy storage technologies used on the grid, regulatory policies and rules provide the framework for the business case and economics of storage systems. Other incentives, such as tax structures and asset depreciation rates significantly affect the economics for storage projects. All the electrical grid-connected storage services, market opportunities, cost-recovery methods, cost-effectiveness criteria, incentives, and rebates are governed by a well-established regulatory oversight. The Federal Energy Regulatory Commission (FERC) regulates interstate transactions, while State entities such as Public Utility Commissions (PUCs) regulate utility management, operations, electricity rate structures, and capacity acquisition within their State's jurisdiction. Additionally, in some regions Independent System Operators (ISOs) provide oversight of transmission and generation. This multi-level oversight impacts the growth of the storage industry because policies can create or inhibit market opportunities for electricity storage and may determine how, and if, they will be compensated.

New policies are being implemented at the State level, being discussed and rolled out at the national level, and previous investments are coming to fruition and can shape future investment.[12] As an example of the influence of policy structure on the adoption of storage, FERC Order 755 helps structure payments and set contracts for frequency regulation, and is changing the market for frequency-regulation applications. PJM was the first Regional Transmission Organization (RTO) to adopt Order 755, and the results have significantly improved the commercial viability of frequency regulation. Further, the frequency regulation market will likely continue to mature, as several other RTOs have or are scheduled to adopt Order 755. For example, Midcontinent Independent System Operator (MISO) also adopted the order at the end of 2012, while the California and New York Independent System Operators (CAISO & NYISO) adopted the mandate

[12] Policy information come from the Bloomberg New Energy Finance report on storage dated June, 2013 and the Sandia National Laboratories database: http://www.energystorageexchange.org/

in mid-2013 and the Independent System Operator - New England (ISONE) will begin following the Order in January 2014.[13] Additionally, Congress continues to debate two bills[14] that would help codify the cost structure for storage-related subsidies and partnership taxation structures for investment in storage and storage-related activities.

In addition to national developments, California, Texas, New York, Hawaii, and Washington have all proposed significant policies on storage. California has enacted laws that make energy storage more viable from a cost and regulatory perspective and give the California Public Utilities Commission (CPUC) the power to mandate certain regional penetration levels of storage. The CPUC recently mandated that 50 MW of storage be installed in the Los Angeles Basin by 2020, as well as a top-line mandate of 1.3 GW of storage for the entire state.[15] The Texas legislature has enacted SB 943 that classifies energy storage technologies alongside generation equipment, and the Public Utility Commission of Texas adopted key aspects of the bill as well as clarified rules, requirements, and definitions for energy storage [16]. In 2010, New York State established NY Battery and Energy Storage Technology Consortium (NY-BEST),[17] a public-private partnership that researches storage technology and manufacturing, aids energy storage organizations as well as potential stakeholders, and advocates for policies and programs that could improve energy storage. Additionally, Washington State enacted two laws[18] related to energy storage: the first enables qualifying utilities to credit energy storage output of renewable sourced energy at 2.5 times the normal value; the second requires electric utilities to include energy storage in all integrated resource plans.

On the national level, several projects that were funded under ARRA through the Smart-Grid Demonstration Grant program are coming online in 2013, and their performance has the potential to guide future investment decisions and policy initiatives. In total, an estimated 59 MW of storage capacity is scheduled to come online in 2013, accounting for 7 of the 16 ARRA-funded projects. In addition, hydrogen fuel cells for backup power are being used in more than 800 units associated with telecom towers in the U.S., as a result of ARRA funding.[19]

Internationally, Japan has pursued the development and deployment of energy storage to balance the variability of load on its nuclear power plants. After completing an initial phase of building pumped hydro storage plants, Japan pursued development of other storage technologies. Its most prominent accomplishment was the commercial

[13] See Bloomberg New Energy Finance H1 2013, page 8.
[14] S. 795 and S. 1845
[15] Note that this number includes some of the projects funded by the 2009 ARRA that have yet to come online; these projects total 334MW, or roughly 1/4th of the total target.
[16] http://www.capitol.state.tx.us/billlookup/history.aspx?legsess=82r&bill=sb943
[17] http://www.ny-best.org/
[18] HB 1289 and HB1296
[19] http://www.nrel.gov/hydrogen/cfm/pdfs/arra_deployment_cdps_q12013_4web.pdf

development of high temperature sodium-sulfur batteries through a sustained R&D program that spanned two decades.[20] Today, Japan-based NGK is the only source of sodium-sulfur batteries and as of 2012, NGK had over 450 MW of sodium sulfur storage systems installed.[21]

China and India are also pursuing energy storage programs to support the rapid growth in their electric energy needs. Energy storage could serve many grid needs in both China and India to bridge the gap between available generation and customer loads during system peaks and as a distributed resource on the customer-side of the meter. In one example, India is aggressively pursuing energy storage as a secure power resource for more than 300,000 telecom towers, and announced a $40 million contract in July 2013 for Li-ion battery energy storage systems to meet that need. This example has the potential to demonstrate telecom towers as a "first market" for storage technologies developed and manufactured in the U.S.[22]

Table 1 describes some of the country-specific highlights of international grid storage.

[20] See Bloomberg New Energy Finance H1 2013, pages 19-22.
[21] See Bloomberg New Energy Finance H1 2013, page 23.
[22] http://www.saftbatteries.com/press/press-releases/saft-receives-%E2%82%AC35m-orders-reliance-jio-infocomm-limited-rjil-li-ion-telecom

Table 1 - International Landscape of Grid Storage

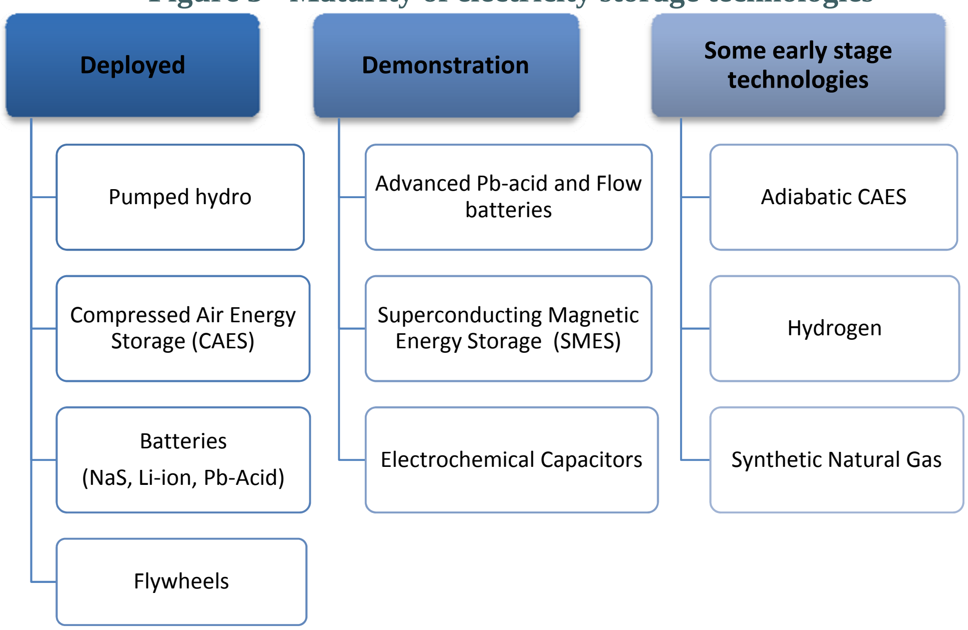
Country	Storage Targets[23]	Projects	Other Issues	Technology & Applications
Italy	75 MW	• 51 MW of Storage Commissioned by 2015 • Additional 24 MW funded	• Italy has substantial renewables capacity relative to grid size, and the grid is currently struggling with reliability issues; additional renewables capacity will only exacerbate this problem	• 35 MW to be Sodium-Sulfur Batteries for long-duration discharge • Additional capacity is focused on reliability issues and frequency regulation
Japan	30 MW	• Approved 30 MW of Lithium-ion battery installations	• Potential decommissioning of nuclear fleet • Large installation of intermittent sources - est. 9.4 GW of solar PV installed in 2013 alone • Several isolated grids with insufficient transmission infrastructure during peak demand periods	• Primarily Lithium ion batteries • Recently increased regulatory approved storage devices from 31 to 55
South Korea	154 MW	• 54 MW lithium-ion batteries • 100 MW CAES	• Significant regulatory/performance issues with nuclear fleet	• Reliability & UPS
Germany	$260m for grid storage	• $172m already apportioned to announced projects	• Decommissioning entire nuclear fleet; Large (and expanding) intermittent renewable generation capabilities • Over 160 energy storage pilot projects • Awaiting information on energy storage mandates	• Hydrogen; CAES & Geological; Frequency Regulation
Canada	-	• Announced 1st frequency regulation plant	-	-
UK	-	• 6 MW multi-use battery	• Other small R&D and Demonstration projects	• Battery will perform both load shifting and frequency regulation applications

[23] Information in this table comes from Bloomberg New Energy Finance's Energy Storage Market Outlook, June, 28, 2013, as well as the DOE database on Energy Storage Projects referenced earlier. Conversions based on 1 euro = $1.30

Technology Overview

Storage systems can be designed with a broad portfolio of technologies such as pumped hydro, compressed air energy storage CAES, a large family of batteries, flywheels, and superconducting magnetic energy storage (SMES). Each technology has its own performance characteristics that makes it optimally suitable for certain grid services and less so for other grid applications. This ability of a storage system to match performance to different grid requirements also allows the same storage system to provide multiple services. This gives storage systems a greater degree of operational flexibility that cannot be matched by other grid resources, such as combustion turbines or a diesel generator. The ability of a single storage system to meet multiple requirements also makes it feasible to capture more than one value stream, when possible, to justify its investment. While the categorization of "deployed," "demonstrated," and "early stage," is often blurred, and changes over time, Figure 3 groups technologies based on their present degree of maturity.[24]

Figure 3 - Maturity of electricity storage technologies



This portfolio of electricity storage technologies can provide a range of services to the electric grid and can be positioned around their power and energy relationship. Established large-scale technologies, such as CAES and pumped hydro, are capable of discharge times in tens of hours and with high module sizes that reach 1,000 MW. Pumped hydroelectric energy storage is a large, mature, and commercial utility-scale technology currently used at many locations in the United States and around the world. Pumped hydro currently employs off-peak electricity to pump water from a reservoir up to another reservoir at a higher elevation. When electricity is

[24] Several technologies that are still in the early stages of research have been omitted, as they are unlikely to be commercially viable within the next 3-5 years.

needed, water is released from the upper reservoir through a hydroelectric turbine into the lower reservoir to generate electricity. New capabilities of pumped hydro, through the use of variable speed pumping, is opening up the potential for the provision of additional services that may be used to assist in the integration of variable generation sources. Projects may be practically sized up to 4,000 MW and operate at about 76%–85% efficiency, depending on design. Pumped hydro plants have long lives, on the order of 50-60 years. As a general rule, a reservoir one kilometer in diameter, 25 meters deep, and having an average head of 200 meters would hold enough water to generate 10,000 MWh. CAES systems are not as "mature" as pumped hydro, but are similar in their use as they store energy in the form of pressurized air, usually in underground caverns. However, both CAES and pumped hydro have very specific geographic requirements making their installation site-dependent.

For example a CAES plant can enhance the grid to allow successful integration of significant amounts of renewable resources while enhancing the transmission system and providing grid stability during intermittent operations. It will also provide ancillary services such as regulation, capacity reserve, and reactive power for voltage support with the size and flexibility that will enable large amounts of energy to be stored and discharged for use to maintain and improve the grid system reliability and relieving transmission congestion. Energy storage, such as CAES enhances the grid by making the grid more efficient, which will assist in achieving the full potential of renewables and will provide an industry model for a grid-enabled diversified energy portfolio.

In contrast to the capabilities of these two technologies, various electrochemical batteries and flywheels are positioned around lower power and shorter discharge times, ranging from a few seconds to six hours, and these technologies can generally be built without specific geographical features at the site.

Table 2 – Installations of Batteries

Battery Type	Number of 1MW+ Deployments	Largest Installation
Lithium Ion	15	40
Sodium Sulfur	11	4*
Lead Acid	9	36

*There are two 4MW deployments

There are several different electrochemical battery technologies that are currently available for commercial applications. These technologies have been successfully deployed in both distributed and centralized applications in various sizes. However, they have not yet realized widespread deployment due to challenges in energy density, power performance, lifetime, charging capabilities, safety, and system cost. The more robust technologies include lithium-ion (Li-ion), sodium sulfur (NaS), and lead acid batteries, including lead carbon batteries. Li-ion batteries tend to be best suited for relatively short discharges (under two hours) and do not handle deep-discharges well, so these batteries are more suited to power-management operations such as frequency regulation or as an uninterruptible power source (UPS). NaS batteries are somewhat behind Li-ion battery technology in terms of energy and power, but they can maintain longer discharges (four to eight hours) and may be more suitable for load leveling and price arbitrage operations. Lead acid batteries, a mature technology with good battery life, are relatively cheap; however, the low energy density and short cycle time are challenges to large-scale deployment. Also, there are other novel chemistries being developed such as sodium-ion.

Flywheels are currently commercially deployed primarily for frequency regulation. Flywheel plants take in electricity and convert it into spinning discs, which can be sped up or slowed down to rapidly shift energy to or from the grid, which ensures steady power (60 Hz) supplied to the grid.

Flow batteries were invented by US utilities specifically to provide MW-scale storage capacity beyond the geographic constraints of hydroelectric facilities. Significant US industry and DOE investment over the past 40 years has led to a mature understanding of the advantages and limitations of available chemistries, as well as more recent breakthroughs in performance and thermal tolerance. However, due to lack of MW-scale field history, flow batteries have not gained substantial commercial traction in the US, with various flow-battery technologies still in the demonstration phase, and the largest single operational system at 0.6 MW.[25] However, recently we are seeing flow batteries projects launch oversees with systems up to 5MW in size and a total deployed capacity of 20MW. China and Japan are currently funding over $200MM in flow battery projects and Europe is following suit with numerous smaller projects. The interest in flow batteries stems from several potential advantages over traditional batteries, primarily the liquid suspension and separation of the chemical components that allow for full charge utilization with a high number of discharge cycles and extremely long unit life. Flow batteries have faced obstacles related to their low energy density and integrated design requirements that make it difficult to compete at sub-MW scale. With recent advances in these areas, flow batteries may be commercially deployable in the US within the next few years if MW-scale projects similar to current ARRA projects succeed.

Another technology in the demonstration/applied research phase is superconductive magnetic energy storage (SMES). Each unit employs a superconducting coil, a power conditioning system, and a cooling system. The cooling system chills the coil below the superconducting transition temperature, so that electrical currents flow without resistance or loss of energy. Energy is stored inductively in the DC magnetic field of a solenoid, as long as the temperature remains sufficiently low. Most SMES technologies currently have a high cycle-life and power density, but low energy density and high cost that make them best suited for supplying short bursts of electricity into the energy system. Superconductors currently have the highest round-

[25] This is the Prudent Energy VRB-ESS® - Gills Onions, California. The information on US installations comes from the DOE Energy Storage database referenced earlier.

trip efficiency of any storage device, though they are costly to manufacture and maintain and they have only a limited number of small demonstrations.

Electrochemical capacitors (EC) technology stores direct electrical charge in the material, rather than converting the charge to another form, such as chemical energy in batteries or magnetic field energy in SMES; this makes the storage process reversible, efficient, and fast. As such, EC can be useful in power-quality applications such as frequency regulation, and voltage stabilization. The devices may have longer useful lives since there is little breakdown in the capacitors ability to store energy electrostatically. Currently, electrochemical capacitors can store significantly more energy than dielectric and electrolytic capacitors; however, EC technology is still cost prohibitive.[26]

Thermochemical energy storage is an emerging technology that uses reversible chemical reactions to store heating or cooling capacity in chemical compounds. The promise of thermochemical storage is the tremendous energy densities that it can achieve over most other storage types, ranging from 5 to 20 times greater than conventional storage. Due to its relatively high energy density potential, a significant research and development effort is currently being focused on this type of thermal energy storage, though deployments are limited.

Hydrogen systems, as with the other storage technologies, require careful analysis to fully capture the value stream. Multiple components such as electrolyzers, fuel cells, or hydrogen oxygen turbines coupled with storage, either underground in geologic formations or above ground in hydrogen tanks, can be used in grid systems. Hydrogen can also allow for the decoupling of electricity production and storage resulting in flexible operation. While round trip energy efficiencies might be at a level of 40%, this relatively low efficiency is balanced by energy storage potential that may last days, to weeks, or longer.

Table 3 summarizes the state of most energy storage technologies.

Table 3 - Technology Types Source: Advancing Energy Storage

Technology	Primary Application	What we know currently	Challenges
CAES	• Energy management • Backup and seasonal reserves • Renewable integration	• Better ramp rates than gas turbine plants • Established technology in operation since the 1970's	• Geographically limited • Lower efficiency due to roundtrip conversion • Slower response time than flywheels or batteries • Environmental impact
Pumped Hydro	• Energy management • Backup and seasonal reserves • Regulation service also available through variable speed pumps	• Developed and mature technology • Very high ramp rate • Currently most cost effective form of storage	• Geographically limited • Plant site • Environmental impacts • High overall project cost

[26] Source: http://web.anl.gov/energy-storage-science/publications/EES_rpt.pdf

Technology	Primary Application	What we know currently	Challenges
Fly wheels	• Load leveling • Frequency regulation • Peak shaving and off peak storage • Transient stability	• Modular technology • Proven growth potential to utility scale • Long cycle life • High peak power without overheating concerns • Rapid response • High round trip energy efficiency	• Rotor tensile strength limitations • Limited energy storage time due to high frictional losses
Advanced Lead-Acid	• Load leveling and regulation • Grid stabilization	• Mature battery technology • Low cost • High recycled content • Good battery life •	• Limited depth of discharge • Low energy density • Large footprint • Electrode corrosion limits useful life
NaS	• Power quality • Congestion relief • Renewable source integration	• High energy density • Long discharge cycles • Fast response • Long life • Good scaling potential	• Operating Temperature required between 250° and 300° C • Liquid containment issues (corrosion and brittle glass seals)
Li-ion	• Power quality • Frequency regulation	• High energy densities • Good cycle life • High charge/discharge efficiency	• High production cost - scalability • Extremely sensitive to over temperature, overcharge and internal pressure buildup • Intolerance to deep discharges
Flow Batteries	• Ramping • Peak Shaving • Time Shifting • Frequency regulation • Power quality •	• Ability to perform high number of discharge cycles • Lower charge/discharge efficiencies • Very long life	• Developing technology, not mature for commercial scale development • Complicated design • Lower energy density
SMES	• Power quality • Frequency regulation	• Highest round-trip efficiency from discharge	• Low energy density • Material and manufacturing cost prohibitive
Electrochemical Capacitors	• Power quality • Frequency regulation	• Very long life • Highly reversible and fast discharge	• Currently cost prohibitive
Thermochemical Energy Storage	• Load leveling and regulation • Grid stabilization	• Extremely high energy densities	• Currently cost prohibitive

3.0 Grid Scale Energy Storage Applications

Until the mid-1980s energy storage was viewed by the electric utilities as a means to time shift energy produced by coal and nuclear units during off-peak hours to displace energy that would be produced from other more expensive fuels during on-peak periods. Several factors, including environmental concerns in building large pumped hydro plants and the emergence of other storage technologies using batteries and flywheels, introduced the viability of using storage to provide other grid services.[27]

The 2013 edition of the DOE/EPRI Electricity Storage Handbook describes eighteen services and applications in five umbrella groups, as listed in Table 4. The services and applications identified in this table show that energy storage can be used to support generation, transmission, and distribution, as well as customer-side-of-the-meter needs of the grid. This section describes some of the functions most commercially viable and relevant to the near-term future of the grid. [28]

Table 4 – Electric Grid Energy Storage Services

Service Group	Service
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

Recognizing energy storage can have multiple services within the grid allows it to capture multiple benefit streams to offset system costs. The flexibility of storage can be leveraged to provide multiple or stacked services, or use cases, with a single storage system that captures several revenue streams to achieve economic viability. How these services are stacked depends on the location of the system within the grid and the storage technology used. However, due to regulatory and operating constraints, stacking services is a process that requires careful planning and should be considered on a case-by-case basis. The following are brief discussions of some applications of grid energy storage:

Electric Energy Time-shift (Arbitrage)

Electric energy time-shift involves purchasing inexpensive electric energy, available during periods when prices or system marginal costs are low, to charge the storage

[27] A grid service, or application, is a use whereas a benefit connotes a value. A benefit is generally quantified in terms of a monetary or financial value.
[28] A more comprehensive discussion of energy storage applications at all levels can be found in two documents referenced elsewhere in this report: Eyer (2010) and Chapter 1 of the DOE/EPRI 2013 Handbook.

system so that the stored energy can be used or sold at a later time when the price or costs are high. Alternatively, storage can provide similar time-shift duty by storing excess energy production, which would otherwise be curtailed, from renewable sources such as wind or photovoltaic (PV). The functional operation of the storage system is similar in both cases, and they are treated interchangeably in this discussion.

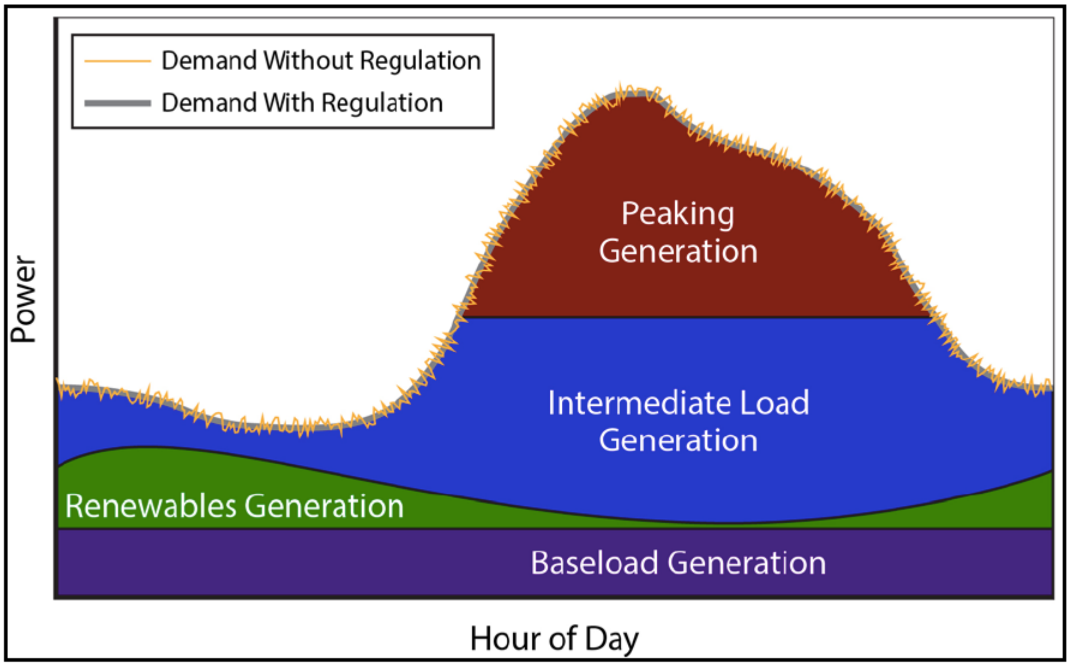
Ancillary Services: Regulation & Frequency Response

Regulation is one of the ancillary services for which storage is especially well suited. Regulation involves managing interchange flows with other control areas to match closely the scheduled interchange flows and momentary variations in demand within the control area. The primary reasons for including regulation in the power system are to maintain the grid frequency and to comply with the North American Electric Reliability Council's (NERC's) Real Power Balancing Control Performance (BAL001) and Disturbance Control Performance (BAL002) Standards, which are mandatory reliability standards approved by FERC

Regulation is used to reconcile momentary differences caused by fluctuations in generation and loads. Regulation is used for damping of that difference. Consider the example shown in Figure 4: the load demand line shows numerous fluctuations depicting the imbalance between generation and load without regulation. The thicker line in the plot shows a smoother system response after damping of those fluctuations with regulation.

Generating units that are online and ready to increase or decrease power as needed are used for regulation and their output is increased when there is a momentary shortfall of generation to provide up regulation. Conversely, regulation resources' output is reduced to provide down regulation when there is a momentary excess of generation. An important consideration in this case is that large thermal base-load generation units in regulation incur some wear and tear when they provide variable power needed for regulation duty.

Figure 4 - System Load Without and With Regulation



Frequency response is very similar to regulation, except it reacts to system needs in even shorter time periods of less than a minute to seconds when there is a sudden loss of a generation unit or a transmission line. As shown in Figure 5,[29] various generator response actions are needed to counteract this sudden imbalance between load and generation to maintain the system frequency and stability of the grid. The first response within the initial seconds is the primary frequency control response of the governor action on the generation units to increase their power output as shown in the lower portion of the figure. This is followed by the longer duration secondary frequency control response by the AGC that spans the half a minute to several minutes shown by the dotted line in the lower portion of Figure 5. It is important to note that the rate at which the frequency decays after the triggering event – loss of generator or transmission – is directly proportional to the aggregate inertia within the grid at that instant. The rotating mass of large generators and/or the aggregate mass of many smaller generators collectively determines this inertia.

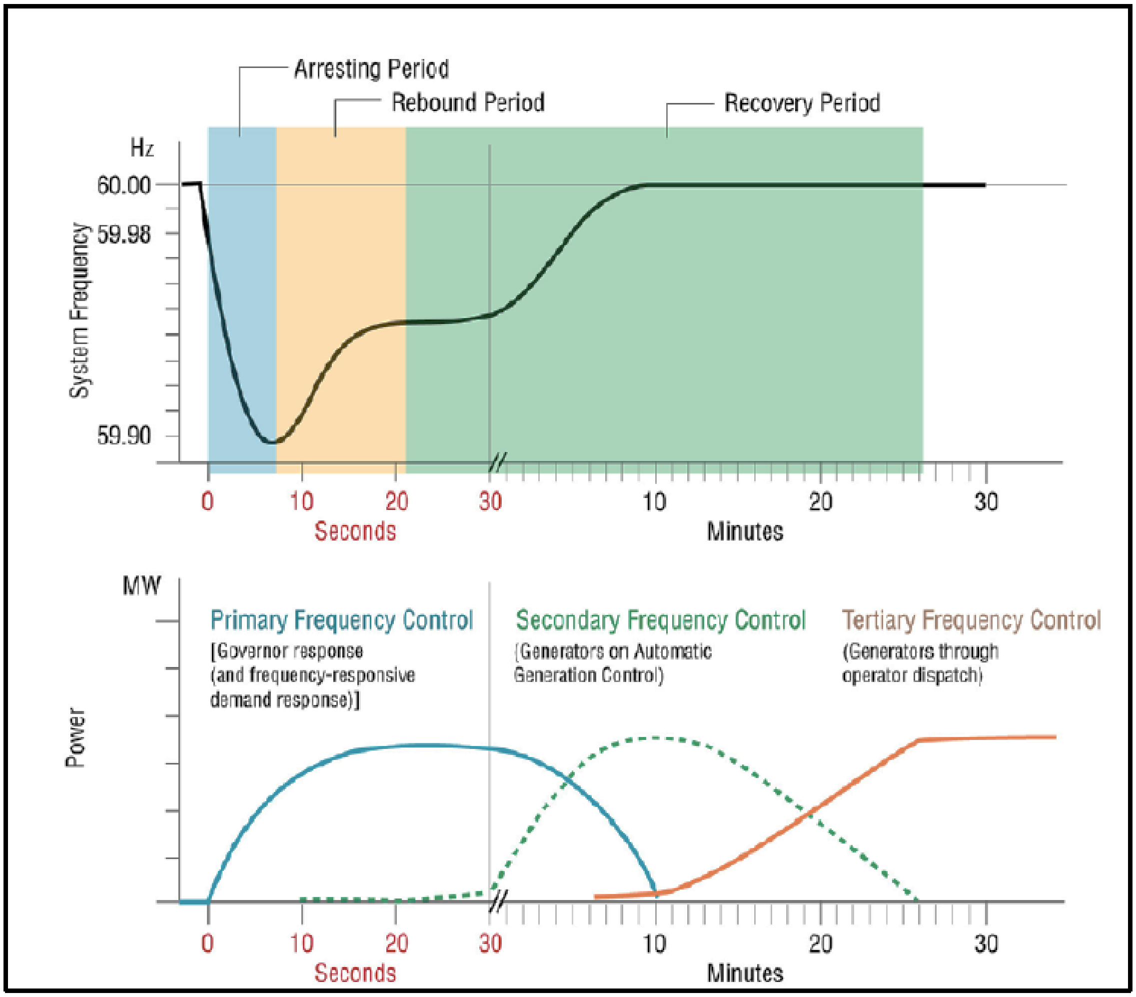
The combined effect of inertia and the governor actions determines the rate of frequency decay and recovery shown in the arresting and rebound periods in the upper portion of Figure 5. This is also the window of time in which the fast-acting response of flywheel and battery storage systems excels in stabilizing the frequency. The presence of fast-

---

[29] *"Use of Frequency Response Metrics to Assess the Planning and Operating Requirements for Reliable Integration of Variable Renewable Generation,"* Joseph H. Eto (Principal Investigator) et al., LBNL-4142E, Lawrence Berkeley National Laboratory, Berkeley, CA, December 2010. http://www.ferc.gov/industries/electric/indus-act/reliability/frequencyresponsemetrics-report.pdf

acting storage assures a smoother transition from the upset period to normal operation if the grid frequency is within its normal range.

Figure 5 - The Sequential Actions of Primary, Secondary, and Tertiary Frequency Controls Following the Sudden Loss of Generation and Their Impacts on System Frequency



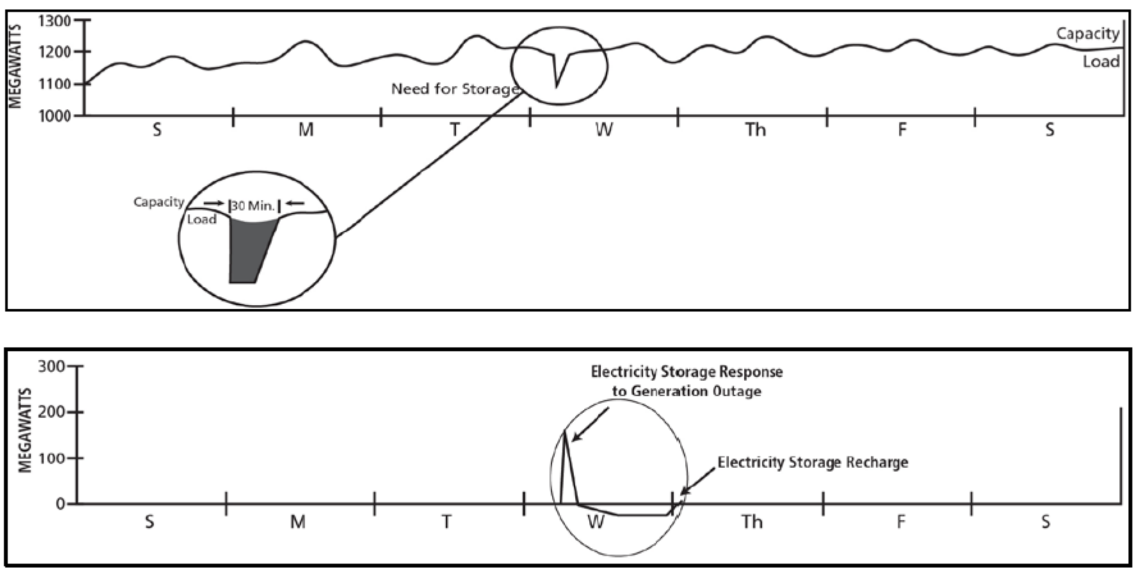
Spinning, Non-Spinning, and Supplemental Reserves

Operation of an electric grid requires reserve capacity that can be called upon when some portion of the normal electric supply resources become unavailable unexpectedly.

Generally, reserves are at least as large as the single largest resource (e.g., the single largest generation unit) serving the system and reserve capacity is equivalent to 15% to 20% of the normal electric supply capacity. NERC and FERC define reserves based on different operating conditions. There are three generic types of reserves: spinning or synchronized reserves[30] that can respond within 10 seconds to 10 minutes to service frequency issues, or generation or transmission outages; non-spinning or non-synchronized reserves[31] that can respond within 10 minutes for use as uninterruptible and/or curtailable loads; and supplemental reserves that can pick up load within an hour to back up any disruption to spinning and non-spinning reserves. Importantly for storage, generation resources used as reserve capacity must be online and operational (i.e., at part load). Unlike generation, in almost all circumstances, storage used for reserve capacity does not discharge at all; it just has to be ready and available to discharge when needed.

Reserve capacity resources must receive and respond to appropriate control signals. Figure 6 shows how storage responds to spinning reserve requirements. The upper plot shows a loss of generation and the lower plot shows the immediate response with a 30-minute discharge to provide the reserve capacity until other generation is brought online.

Figure 6 - Storage for Reserve Capacity



Load Following/Ramping Support for Renewables

Electricity storage is eminently suitable for damping the variability of wind and PV systems and is being widely used in this application. Technically, the operating requirements for a storage system in this application are the same as those needed for a storage system to respond to a rapidly or randomly fluctuating load profile. Most renewable applications with a need for storage will specify a maximum expected up- and

---

30 Spinning reserve is defined in the NERC Glossary as "Unloaded generation that is synchronized and ready to serve additional demand."
31 Non-spinning reserve is not uniformly the same in different reliability regions. It generally consists of generation resources that are offline, but could be brought online within 10 to 30 minutes and could also include loads that can be interrupted in that time window.

down-ramp rate in MW/minute and the time duration of the ramp.[32] This design guidance for the storage system is applicable for load following and renewable ramp support.

Load following is characterized by power output that generally changes as frequently as every several minutes. [33] The output changes in response to the changing balance between electric supply and load within a specific region or area. Output variation is a response to changes in system frequency, timeline loading, or the relation of these to each other that occurs as needed to maintain the scheduled system frequency and/or established interchange with other areas within predetermined limits. A simple depiction of load following was shown in Figure 4 above.

Storage can alleviate some of the cycling of power plants through frequency regulation and other short-term power management techniques. Energy storage technologies can perform better than the existing system as recognized by FERC Order 755. They can potentially achieve efficiencies of 70 to 95 percent while operating at partial capacity with lower efficiency penalties while still maintaining near-instantaneous response times.

Distribution Upgrade Deferral and Voltage Support

Distribution upgrade deferral involves using storage to delay or avoid investments that would otherwise be necessary to maintain adequate distribution capacity to serve all load requirements. The upgrade deferral could be a replacement of an aging or over-stressed existing distribution transformer at a substation or re-conducting distribution lines with heavier wire.

When a transformer is replaced with a new, larger transformer, its size is selected to accommodate future load growth over the next 15- to 20-year planning horizon. Thus a large portion of this investment is underutilized for most of the new equipment's life. The upgrade of the transformer can be deferred by using a storage system to offload it during peak periods, thus extending its operational life by several years. Notably, for most nodes within a distribution system, the highest loads occur on just a few days per year, for just a few hours per year. Often, the highest annual load occurs on one specific day with a peak somewhat higher than any other day. One important implication is that storage used for this application can provide significant benefits with limited or no need to discharge.[34] Further, if the storage system is containerized, then it can be physically moved to other substations where it can continue to defer similar upgrade decision points. Additionally, deferring investment decisions reduces the burden of forecasting future increases in load demands; by delaying infrastructure and capacity investments, storage can bridge load

---

[32] Swings of more than 100 MW, roughly the same capacity as a small power plant, can occur within a single five-minute period. The peak 5-minute wind generation down-ramp experience occurred in June 2008 by the Bonneville Power Administration, having a value of -725MW.
[33] Eyer and Corey, 14.
[34] Similarly, this strategy could facilitate taking equipment out of service for maintenance.

demand in areas that see high demand growth or obviate investment where demand growth is below forecast.

Also, a storage system that is used for upgrade deferral could simultaneously provide voltage support on the distribution lines. Utilities regulate voltage within specified limits[35] by tap changing regulators at the distribution substation and by switching capacitors to follow load changes. This is especially important on long, radial lines where a large load such as an arc welder or a residential PV system may be causing unacceptable voltage excursions on neighboring customers. These voltage fluctuations can be effectively damped with minimal draw of real power from the storage system.

Customer Side of the Meter Storage

Increasingly, deployment of new technologies on the customer side of the meter is changing the electrical nature of customer requirements. And the evolution of the "smart grid" is enabling customers to shape their requirements to improve their own utilization of electricity, while also contributing to improved grid reliability, performance, and economics. These developments create an opportunity for customer storage to play an increasing role in grid services.

Energy storage has been used by customers for many years to achieve either improved reliability or economic benefits. Uninterruptable power supplies have long been used by customers requiring high reliability to provide short-term power to bridge the period between an outage and the start of backup generation. In some cases electrical storage provides backup power as well. More recently, customer systems combining PV and storage have increased because of their ability to improve customer energy economics. As PV systems drop in price, customers will increasingly opt to deploy PV-storage systems. In addition, thermal storage has been utilized for many years to reduce electrical usage during peak periods. And the deployment of electric vehicles (EV) is another form of customer storage of electricity. Co-optimized charging can be conducted in a manner that supports improved grid reliability and economics. Studies are underway now to examine the potential for using EVs as power sources for the grid, essentially in the same manner that utility storage would be. Once retired (nominally when their energy capacity reaches 80% of their initial value), EV batteries can see secondary use, repackaged for providing stationary grid storage (currently being demonstrated by DOE).

In general, energy storage on the customer side of the meter is configured and optimized to meet customer service needs. The value proposition for storage is therefore customer

[35] ANSI C84.1 "American National Standard for Electric Power Systems and Equipment – Voltage Ratings (60 Hz)" establishes nominal voltage ratings for utilities to regulate the service delivery and operating tolerances at the point of use.

specific, but from a grid perspective has primarily been driven by time-of-use rates and demand charges. A residential electric storage unit might be nominally 1.5- 5kW, and 3-20kWh, while a commercial electric storage system would typically range from 10's of kW to multi-megawatt systems. Commercial customers will also acquire electric energy storage for power quality and reliability purposes. As utilities seek to increase the utilization of load to assist grid operation, principally through new market products and incentives for different functions (e.g. regulation and load following services), the value proposition for customer energy storage will evolve and is expected to increase. Similarly, where incentive structures for renewable deployment is joined with energy storage, the internal return on investment for the combined system can be significantly higher than for storage alone[36]. Beyond direct customer benefits (such as comfort or equipment sizing and performance), and absent special incentive structures, energy storage behind the meter will have to compete against utility-sited energy storage for grid services. Hence, cost targets described in Section 5 should serve as a threshold for behind the meter storage when used solely for grid services. In fact, combining grid service benefits with customer service benefits should raise the threshold of affordability for customer storage.

Table 5 on the next page summarizes many of these key applications by energy storage technology.

---

[36] Strategen reported that in California, the IRR for a 100kW 4 hr battery system, increased from 8.2%/yr to 18%/yr when storage was combined with PV generation, due to favorable incentive rate structures. "Energy Storage – Shaping the Future of California's Electric Power System**",** Prepared for DistribuTECH 2011, February 2, 2011, Strategen and California Energy Storage Alliance.

Table 5 - Applications by Technology Type

Application	Description	CAES	Pumped Hydro	Flywheels	Lead-Acid	NaS	Li-ion	Flow Batteries
Off-to-on peak intermittent shifting and firming	Charge at the site of off peak renewable and/ or intermittent energy sources; discharge energy into the grid during on peak periods	◑	◑	○	●	●	●	●
On-peak intermittent energy smoothing and shaping	Charge/discharge seconds to minutes to smooth intermittent generation and/or charge/discharge minutes to hours to shape energy profile	○	◑	◑	●	●	●	●
Ancillary service provision	Provide ancillary service capacity in day ahead markets and respond to ISO signaling in real time	◑	◑	◑	◑	◑	◑	◑
Black start provision	Unit sits fully charged, discharging when black start capability is required	◑	◑	○	●	●	●	●
Transmission infrastructure	Use an energy storage device to defer upgrades in transmission	○	○	○	●	●	●	●
Distribution infrastructure	Use an energy storage device to defer upgrades in distribution	○	○	○	●	●	●	●
Transportable distribution-level outage mitigation	Use a transportable storage unit to provide supplemental power to end users during outages due to short term distribution overload situations	○	○	○	◑	●	●	●
Peak load shifting downstream of distribution system	Charge device during off peak downstream of the distribution system (below secondary transformer); discharge during 2-4 hour daily peek	○	○	○	●	●	●	●
Intermittent distributed generation integration	Charge/Discharge device to balance local energy use with generation. Sited between the distributed and generation and distribution grid to defer otherwise necessary distribution infrastructure upgrades	○	○	○	●	◑	◑	◑
End-user time-of-use rate optimization	Charge device when retail TOU prices are low and discharge when prices are high	◑	◑	○	◑	◑	◑	◑
Uninterruptible power supply	End user deploys energy storage to improve power quality and /or provide back up power during outages	○	○	◑	●	●	●	●
Micro grid formation	Energy storage is deployed in conjunction with local generation to separate from the grid, creating an islanded micro-grid	○	○	○	●	●	●	●

Definite suitability for application ● ; Possible use for application ◑; Unsuitable for application ○

4.0 Summary of Key Barriers

There are four barriers that should be explored to promote the widespread deployment of energy storage:

- Cost competitive energy storage systems
- Validated performance and safety
- Equitable regulatory environment
- Industry acceptance

Cost competitive energy storage systems: The total cost of storage systems, including all the subsystem components, installation, and integration costs need to be cost competitive with other non-storage options available to electric utilities. While there is a strong focus on reducing the cost of the "storage" components, such as batteries or the flywheel, the storage component still constitutes only 30% to 40% of the total system cost, thus the focus needs to be on the entire system.

Additionally, there is a concurrent need to quantify the "value" of storage in the various services it provides to the grid, individually and in multiple or "stacked" services, where a single storage system has the potential to capture several revenue streams to achieve economic viability. This is important now and as the cost of storage systems decline to economically attractive levels.

Validated performance and safety: The process for evaluating and reporting the performance of existing storage systems on a unified basis needs to be created. This combined with industry accepted codes and standards to specify desired performance parameters for each storage service, will lead to a wider acceptance of energy storage systems. For example, there is significant uncertainty over the usable life of batteries[37] and the length of time that a storage installation can generate revenue; both of these issues directly impact investment calculations. According to stakeholder input, a fuller understanding of the true life of batteries through demonstrations and accelerated testing could help remove this barrier, since predicting reliability through improved testing is important in supporting commercialization.

The operational safety of large storage systems is a concern and will be a barrier in their deployment in urban areas or in proximity of other grid resources such as substations. Design practices that incorporate safety standards and safety testing procedures for the different storage technologies need to be developed and codified.

[37] For example, at a recent roundtable with several key stakeholders from utilities and energy companies, there was particular skepticism over claims of 20-years of high-efficiency charging/discharging that some battery manufacturers claim.

Equitable Regulatory Environment: Currently, a consistent pricing or market plan for providing grid storage does not exist and the uncertainty surrounding use-case economics inhibits investment. Without an established revenue generation model for storage operators, the case for investment will remain muted. While there have been demonstrations in areas such as frequency regulation, there are still enough revenue uncertainties in other applications to dissuade investment.

Industry Acceptance: There is also significant uncertainty about how storage technology will be used in practice and how new storage technologies will perform over time in applications. Currently, systems operators have limited experience using deployed storage resources; stakeholder input suggests that development of algorithms to employ storage technology effectively and profitably could encourage investments. Similarly, today's utility planning, transmission and distribution design tools do not have the capability to analyze energy storage as an option on a consistent basis. Integrating storage into the planning tools that are currently used by industry (rather than developing stand-alone tools) could boost storage technologies.

These four challenges were addressed during a recent DOE-sponsored workshop/webinar on energy storage, where industry and academic participants also noted:

- Balance of system costs are critically important and further analysis and research is needed to reduce them
- There should be a focus on manufacturability and reliability, and companies that have produced a viable application should receive support for manufacturing improvements
- Coordination is required to inform standard setting organizations regarding uniformity in product performance and interfaces
- There should be a thorough analysis of completed ARRA projects; successful ARRA projects should be encouraged to continue with commercial deployment of their technology, and they should be part of a regular pathway to continue projects leading to commercialization-ready prototypes.

5.0 Energy Storage Strategic Goals

The vision for the electricity system of the future includes a significant scale-up of clean energy and energy efficiency that balances environmental and energy goals with impacts on consumer costs and economic productivity. The adoption of technology for the two-way flow of energy and communications would open up access to information, participation, choice, and empower consumers with options from using electric vehicles to producing and selling electricity. The future grid will provide a coordinated balance between centralized, decentralized and automated control including interactions with microgrids, and while it becomes increasingly accessible to new technologies and innovation, it will remain reliable and secure against cyber and physical threats, and be resilient to disruptions and outages.

Given the important role energy storage will have in future electricity systems, a strategy for storage depends on focusing on how ***that energy storage technologies should be cost competitive (unsubsidized) with other technologies providing similar services; that energy storage should be recognized for its value in providing multiple benefits simultaneously; and that ultimately, storage technology should seamlessly integrate with existing systems and sub-systems leading to its ubiquitous deployment***.

In reviewing the barriers and challenges, and the future for energy storage, a ***strategy*** that would address these issues should comprise three broad outcome-oriented goals:

1. Energy storage should be a broadly deployable asset for enhancing renewable penetration – specifically to enable storage deployment at high levels of new renewable generation
2. Energy storage should be available to industry and regulators as an effective option to resolve issues of grid resiliency and reliability
3. Energy storage should be a well-accepted contributor to realization of smart-grid benefits – specifically enabling confident deployment of electric transportation and optimal utilization of demand-side assets.

To realize these outcomes, the principal challenges should be addressed as described in Section 4.0 above. To that end:

- **Cost competitive energy storage technology** - Achievement of this goal requires attention to factors such as life-cycle cost and performance (round-trip efficiency, energy density, cycle life, capacity fade, etc.) for energy storage systems as deployed. It is expected that early deployments will be in high value applications, but that long term success requires both cost reduction and the capacity to realize revenue for all grid services storage provides.
- **Validated reliability and safety** - Validation of the safety, reliability, and performance of energy storage is essential for user, investor and insurer confidence.

- **Equitable regulatory environment** – Value propositions for grid storage depend on reducing institutional and regulatory hurdles to levels comparable with those of other grid resources.
- **Industry acceptance** – Industry adoption requires that they have confidence storage will deploy as expected, perform and deliver as predicted and promised.

DOE has conducted workshops[38] with industry, and have developed the following cost and performance targets for near-term and long-term storage technology development for the grid:

Near-term

- Demonstrate AC energy storage systems involving redox flow batteries, sodium-based batteries, lead-carbon batteries, lithium-ion batteries and other technologies to meet the following electric grid performance and cost targets:[39]
  - System capital cost: under $250/kWh
  - Levelized cost: under 20 ¢/kWh/cycle
  - System efficiency: over 75%
  - Cycle life: more than 4,000 cycles
- Develop and optimize power technologies to meet AC energy storage system capital cost targets under $1,750/kW

Long-term[40]

- Research and develop new technologies based on advanced materials and chemistries to meet the following AC energy storage system targets:
  - System capital cost: under $150/kWh
  - Levelized cost: under 10 ¢/kWh/cycle (i.e., economically scalable without subsidies)
  - System efficiency: over 80%
  - Cycle life: more than 5,000 cycles
- Develop and optimize power technologies to meet AC energy storage system capital cost targets under $1,250/kW
- For Concentrated Solar Power (CSP)-storage systems:
  - System capital cost: under $15/kWh
  - System efficiency: 95%

---

[38] 1) Electric Power Industry Needs for Grid-Scale Storage Applications, Prepared by Nexight Group, Sponsored by U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, and the Office of Energy Efficiency and Renewable Energy, Solar Technologies Program, and 2) Advanced Materials and Devices for Stationary Electrical Energy Storage Applications, Prepared by Nexight Group, Sponsored by U.S. Department of Energy Office of Electricity Delivery and Energy Reliability, and the Advanced Research Projects Agency, December 2010.

[39] For current cost information, see Chapter 2 of Akhil, A.A., Huff, G, Currier, A.B., Kaun, B.C, Rastler, D.M., Chen, S.B., … , Gauntlett, W.D. (2013). DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA. *Sandia National Laboratories Report,SAND2013-5131*.

[40] For current cost information, see Chapter 2 of Akhil, A.A., Huff, G, Currier, A.B., Kaun, B.C, Rastler, D.M., Chen, S.B., … , Gauntlett, W.D. (2013). DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA. *Sandia National Laboratories Report,SAND2013-5131*.

– Cycle life: 10,000 cycles

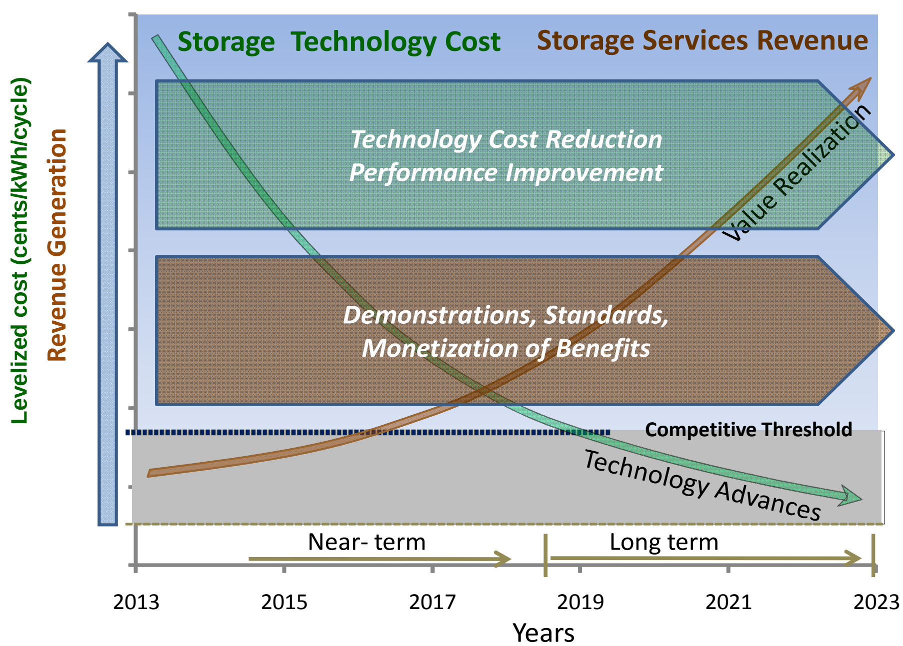
An excellent discussion of the current attributes of many grid storage technologies are provided in the Electric Storage Handbook, reference 39, which was prepared in conjunction with the Electric Power Research Institute and the National Rural Electrical Cooperative Association. The information provided in the Handbook offers insight on the attributes of specific storage technologies. No technology currently meets all metrics; however, each technology has attributes that allow it to approach some metrics. In some markets, current technologies, which do not satisfy all the metrics, are already commercially viable. DOE's strategy to achieve these goals is outlined in Table 6.

Table 6 - Strategy Summary for DOE Energy Storage

Challenge/Goal	Strategy Summary
Cost competitive AC energy storage systems	• Targeted scientific investigation of fundamental materials, transport processes, and phenomena enabling discovery of new or enhanced storage technologies • Materials and systems engineering research to resolve key technology and system cost and performance challenges of known and emerging storage technologies (including manufacturing) • Seeded technology innovation of new storage concepts • Development of storage technology cost models to guide R&D and assist innovators • Resolution of grid benefits of energy storage to guide technology development and facilitate market penetration
Validated reliability and safety	• Enhancement of R&D programs focused on degradation and failure mechanisms and their mitigation, and accelerated life testing • Development of standard testing protocols and independent testing of prototypic storage devices under accepted utility use cases • Track, document, and make available performance of installed storage systems
Equitable Regulatory Environment	• Collaborative public-private sector characterization and evaluation of grid benefits of storage • Exploration of technology-neutral mechanisms for monetizing grid services provided by storage • Development of industry and regulatory agency-accepted standards for siting, grid integration, procurement, and performance evaluation
Industry acceptance	• Collaborative, co-funded field trials and demonstrations enabling accumulation of experience and evaluation of performance – especially for facilitating renewable integration and enhanced grid resilience • Adaptation of industry-accepted planning and operational tools to accommodate energy storage • Development of storage system design tools for multiple grid services

The general strategy can be summarized as follows: Technology costs are driven down by focused research across a broad array of technologies. Storage provides a suite of application benefits, yet those benefits are not fully monetized. Therefore, efforts also focus on enabling realization of those benefits, their value, and enabling those who deploy storage to receive appropriate financial compensation. Even if financially prudent, deployment won't occur unless users (utilities and customers) and utility regulators have confidence in technology safety, reliability and performance. Hence a strategy that pursues collaborative field demonstrations; modification of design; planning; and operational tools; standardization; and equitable regulatory treatment; serves to gain confidence and reduce barriers to storage deployment. Figure 7 depicts the outcome of this general strategy.

Figure 7 --Storage Technology Cost



RPS requirements imply some 20% renewable generation by 2020. A PNNL study shows that this corresponds to some 18.6 GW of intra-hour balancing required for grid stability. Energy storage, demand response, and fast gas turbines can cover this need. A contribution of 5GW for energy storage is a reasonable lower bound. In addition, estimates by Pike Research set new deployment of energy storage at 14GW worldwide by 2022. This indicates that ***deployment of 5 GW of new grid storage by 2025 is an achievable objective***[41]**.**

[41] National Assessment of Energy Storage for Grid Balancing and Arbitrage PNNL-21388 (2013)

6.0 Implementation of Goals

The issues, strategy, and goals described above are a framework to guide the deployment of energy storage.

DOE sponsors research, development, and demonstrations across multiple offices. The Office of Science/Basic Energy Science, the Office of Energy Efficiency and Renewable Energy, the Advanced Research Projects Agency for Energy, and the Office of Electricity Delivery and Energy Reliability, as well as the office of the Under Secretary for Science & Energy, all actively participate in energy storage programs. See Appendix A for brief descriptions of related activities in each office.

The general roles of these offices relative to the risk and technology readiness are illustrated in Figure 8 and Table 7. In energy storage, as in many other technologies, as risk is reduced and technology matures, the private sector and those public sectors active in deployment take on greater roles and responsibilities. DOE's role changes from that of providing scientific and technology advances during the early stages of technology development to one of independent analyst, convener, and facilitator addressing common issues affecting technology adoption.

Figure 8 -- Role of DOE Offices in Technology Development, Maturation and Commercialization

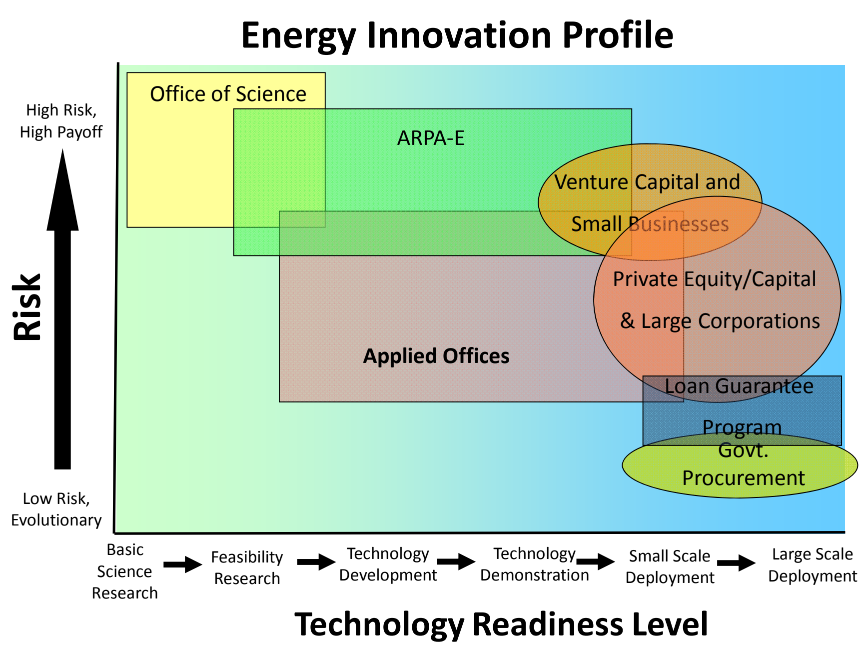


Table 7 - Role of DOE Offices in Grid Energy Storage

OFFICE	Role
OE	Energy storage technology research, development, modeling, demonstration and control technologies that can increase the flexibility and resilience of the electrical grid), from the generator to the consumer, thereby allowing for grid integration of a greater diversity of technologies. This includes microgrids with storage, including for emergency preparedness.
EERE	R&D and demonstrations of on-site energy storage technologies that enable penetration of EERE technologies (generation, efficiency, or transportation) into the current system (grid). Additionally, removal of siting and permitting challenges faced by pumped storage deployment and the evaluation of how variable speed pumped storage can provide ancillary services and add to system flexibility.
ARPA-E	High risk R&D to prove & prototype disruptive new energy storage technologies.
SC-BES	Fundamental research to (i) design and develop novel materials and concepts and (ii) probe physical and chemical phenomena associated with electrical energy storage.
LPO	Debt financing of commercial energy projects which include innovative storage technologies.

Strategy Implementation

The DOE strategic goals may be pursued by a coordinated suite of efforts, summarized below in Table 8. While a specific DOE activity may be primarily to accomplish one goal, many activities contribute to achieving multiple goals. For instance, fundamental materials research helps achieve lower cost and higher performance storage with long service life, but also will contribute to the establishment of standards for accelerated cycle life testing. Similarly demonstration projects, as acknowledge by EPRI and industry broadly, support improvements in system reliability, performance, value discovery, grid integration standards, and refinement of planning and operational tools.

Each Office will utilize their existing processes for engaging participants. These processes include workshops, funding opportunity announcements, small business innovation research grants, co-funding arrangements, and tasking within the Department or with National Laboratories. The coordination of these activities will take place on two levels: first, at the staff level where experts from individual Offices support and review activities undertaken by other Offices; and second, at the Assistant Secretary level, where coordination meetings and communications will ensure that all activities are focused on the major strategic objectives.

Table 8 - Specific Activities in Support of the Energy Storage Strategy

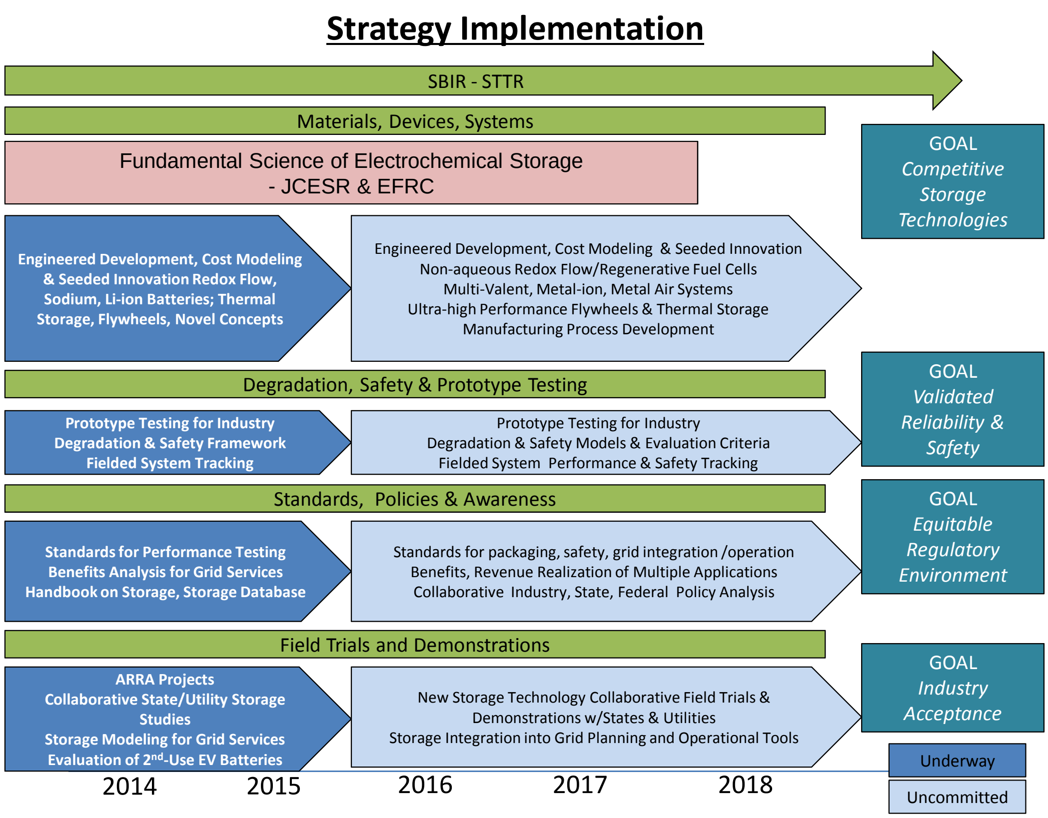
Cost Competitive Energy Storage Technology	• Advanced redox-flow battery chemistry and component development to utilize lower cost membranes, electrodes, bi-polar plates; increase energy (electrolyte composition) and power density (ion flux across the membrane); develop non-aqueous redox-flow – bench scale test of potential $250/kW system • Bench demonstration of low temperature sodium (Na) batteries with efficiency of 90%– metal halide, and Na-ion systems • Demonstration at relevant scale of 2nd use automotive, and safer, longer-lived stationary Li-ion systems • Bench demonstration of multi-cell Mg-ion batteries for stationary applications • Develop and test high performance nano-material-based flywheel components • Advanced SiC, GaN, and AlN-based power converters for storage applications • Develop and test new capacitor materials and structures Use directed advanced research for • Flywheels: Thick cross section carbon fiber composite structure formation; magnetically levitated system enabling technology research, new nano-structured flywheel and magnet materials • CAES: Proof-of-scientific- concept isothermal CAES research; • Electrochemical: novel low cost, high cycle life anode, cathode, electrolyte and separator materials and structure research • Flow-Batteries: High current density, low cost power modules, long cycle-life low-cost electrodes, membranes and catalysts; alkaline exchange membrane electrodes and multi-functional power/energy electrodes; semi-solid flow-able anolyte/catholytes; nanostructured electrode assemblies • Superconductors: low cost high-temperature superconducting materials; high-field coil configurations • Capacitors: High surface area, nanostructured ultracapacitors, low cost, safe, and stable electrolytes/solvents • Power electronics: Novel inverter/converter topologies; integrated passive components; high voltage wide bandgap semiconductor epitaxial materials • Batteries: Low-cost/high energy density batteries; rechargeable metal-air chemistries; in-situ sensors and control technologies; model predictive cell control algorithms; moldable energy storage structures; multi-functional storage chemistries
	• Benefit/cost analysis grid integration of storage for grid resilience, emergency response, renewable deployment, and improved asset utilization • Storage cost models (including manufacturing) to guide R&D and for industry use • Development of design tools for optimally serving multiple applications • Baseline techno-economic modeling of advanced research impacts; value-proposition development for emerging technology research results; first-market analysis for subsequent technology insertion; partnership formation for direct private sector or other governmental

	hand-offs
Validated Reliability & Safety	• Independent testing of prototype storage materials, components and devices in both lab and field systems • Forensic investigation of degraded storage from materials to systems • Degradation, failure, and safety processes/mechanisms characterization and models • Validation of accelerated life-cycle testing protocols • Documentation of field demonstrations regarding performance • Technology specific testing to support hand-offs to governmental and private sector partners, following initial de-risking of advanced research concepts • User facility for validation and testing of system performance
Equitable Regulatory Environment	• Documentation of federal, state and local policies affecting storage deployment • Review of IRP and similar regional, state and community analytic processes affecting storage development and deployment • Exploration of alternative policies that may affect technology attributes and deployment • Support development of consensus based codes and standards for performance, safety, packaging, cycle life, control and grid integration of storage
	• Maintenance of publicly available information on storage technology and attributes affecting its deployment • Dissemination of comprehensive information on storage technology status, experience (e.g., ARRA projects), and realizable contributions to grid resilience, emergency response, renewable deployment, and asset utilization • Provide best practices for installation and use of energy storage to regulators, policy makers, and industry
Industry/ Stakeholder Acceptance	• Conduct analyses and develop tools assessing the beneficial role of storage in cost-effectively achieving higher levels of renewable deployment Provide independent analytic support to public-private sector studies and field trials/demonstrations characterizing the benefits and costs of storage to facilitate renewable deployment
	• Collaborate with industry on enhancement of production cost models, transient event, and other grid simulation/analysis tools to accurately incorporate storage particularly to address enhanced resilience, emergency response, and renewable integration • Collaborate with industry on development of operations and control tools and algorithms that facilitate optimal utilization of storage • Researching mathematical models and algorithms for real-time optimal AC power-flow control and grid topology control optimization, including consideration of storage • Collaboratively address environmental uncertainties through partnered projects with the Dept. of Interior and the Army Corps of Engineers to improve water quality modeling and analysis tools for greater operational flexibility of pumped storage and hydropower projects
	• Collaborate with industry in prototype testing in controlled test bed(s) • Report results from ARRA projects incorporating storage. Collaborate with industry, States, DOD and other stakeholders on field trials and demonstrations of new or improved storage technologies, alternative deployment environments, enable evaluation of a range of grid applications/services or explore grid integration and operation/control approaches • Interface with private-sector financial institutions in the underwriting of innovative commercial energy storage projects applying to the DOE loan program.

DOE supports research and development of a wide array of battery technologies (and other storage types). These technologies are at various levels of technical maturity and developmental risk. For those technologies that are relatively mature, the performance and cost attributes (as well as others like safety) are relatively well characterized, as are key areas where advancement will have the greatest potential impact on their deployment. The Energy Storage Handbook, cited on page 33, provides information to construct comparative mappings to other technologies and grid applications.

Figure 9 below shows, nominally, how several activities by different offices could work towards a solution, in this case for competitive storage technology.

Figure 9 – Summary Timeline of DOE Initiatives



In the longer term:

- DOE can continue advancing material science and engineering, electrochemical sciences and engineering, systems engineering, and contribute to further cost reductions and performance improvement of an array of storage technologies. It is expected that the battery portion of this work can focus on such research that will shift toward technologies, like metal-air systems, that are currently at low technology readiness, as other storage technologies currently being developed are either transferred to the commercial sector or are proven to be unable to achieve competitive cost/performance. Power electronics efforts can expand into ultra-wide band gap materials to push efficiency bounds. DOE is also continuing to advance thermal energy storage and advanced heat transfer fluids for CSP applications.

- DOE can continue to refine our understanding of degradation and failure mechanisms, assist industry in translating that understanding into safer, more reliable and higher performing storage technology, and monitor fielded storage systems to factor experience into the DOE research and development efforts.
- DOE can resolve emerging standards challenges associated with accommodation of life-cycle testing, adaptation of standards and regulatory practices to new types of storage technologies, and harmonization of U.S. and international standards. DOE can monitor the evolving regulatory landscape to ensure its technology development and analytic efforts are consistent with and supportive of equitable regulatory practices.
- DOE can continue to collaborate with industry and other Federal and State entities to facilitate field testing of new storage technologies, update industry planning and operational tools to incorporate improved knowledge on grid storage technologies, and provide updated and improved models of the grid to enable optimization of storage system design.

<u>Joint Center for Energy Storage Research (JCESR)</u>

The JCESR is an innovation hub of the Department of Energy and led by Argonne National Laboratory. The JCESR brings together researchers from four additional DOE National Labs, five research universities, and four private firms. The Center advances next-generation battery technology through basic research using nanoscience tools, pursuing understanding of electrochemical materials and phenomena at the atomic and molecular level.

JCESR has focused research on several goals set for the next five years. By pursuing higher charge densities, new electrodes, and liquid suspension batteries, the group has a target of a five-fold increase in energy stored in today's batteries at one-fifth the cost. Currently, their research is focused on working with high-charge ions (magnesium & yttrium), improved chemical transformations, and improving non-aqueous redox flow (flow batteries). The science from JCESR will impact both transportation and grid applications.

Internal Collaboration

The DOE offices collaborate internally to raise the visibility of the issues, focus resources where they are needed and ensure that R&D results and industry needs are broadly communicated and employed to guide related R&D among all offices. In addition to the already considerable collaboration between staff—e.g., where DOE experts from one office are asked to help evaluate and consider program direction in another office—there are formal collaboration forums, such as the Grid (Modernization) Technology Team, where programs are coordinated and sometimes jointly funded. Collaborative workshops that enable engagement of the R&D community, industry, States and regulators are held periodically to gain common appreciation of the energy storage development and deployment challenges and opportunities.

While working together, as noted above, each office has clearly defined roles in the development of energy storage components and systems; these roles have evolved over time in alignment with the offices' core competencies. The Office of Science/Basic Energy Sciences (SC-BES), for example, conducts fundamental research into the scientific principles and physical processes underlying the material science and advanced electrochemistry necessary for storage technologies of the future in their "core" research projects, the six Energy Frontier Research Centers that focus on energy storage technology, and the Joint Center for Energy Storage Research—see box above.

The Advanced Research Projects Agency for Energy (ARPA-E) seeks high-risk, high-payoff projects which offer the possibility of significant and rapid developments in relevant technologies, including energy storage.

The Office of Energy Efficiency and Renewable Energy (EERE) focuses on the analysis of storage technologies as they apply to high penetration of renewable generation (e.g., wind, solar), addressing siting , permitting and environmental barriers to pumped hydro storage deployment, development of models to accurately characterize the capabilities of variable speed pumping technologies and the services they can provide, evaluate the techno-economic opportunities for the development of modular pumped hydro storage, and development of energy efficiency technologies particularly for commercial and residential buildings and transportation (including electric vehicles).

The Office of Electricity Delivery and Energy Reliability (OE) focuses on large-scale energy storage systems that can enhance the overall flexibility, reliability, resilience, and capability of the grid, and can enable transformation of the national electric generation and delivery system to meet the reliability and low-carbon emissions goals of the 21st century.

OE and ARPA-E Working Together on Energy Storage

Over the past decade, OE has led DOE grid-scale energy storage, through support of applied research, development, and demonstrations in partnership with companies, universities and national laboratories. ARPA-E was formed over the past 4 years with a focus on early-stage advanced research with high potential for impact across energy sectors. OE and ARPA-E work together to maximize impact and ensure development of new technology into energy storage applications. OE and ARPA-E collaborate on combined workshops; participation in interdepartmental working groups; co-participation in annual Peer-review; and combined on-site reviews for specific projects by OE and ARPA-E technology managers. Specific examples of technologies with coordinated support by ARPA-E and OE include:

Flywheel Energy Storage: OE supported research, development and deployment of flywheel energy storage technology, most notably for a 25kWh/15-minute storage unit. A highlight of this effort is a pioneering ARRA-OE funded 20MW flywheel storage system for grid frequency regulation on the grid. in an array of 25kWh units. To provide a pathway to larger scale, lower cost flywheels at the 100kWh scale, ARPA-E has supported advanced research on higher energy density composite materials, flywheel magnetic levitation and advanced rotor dynamics. This work is in conjunction with an OE project to develop a 4x higher power flywheel drive will enable subsequent development of a 100kWh flywheel

Planar Sodium Metal Halide Battery: Sodium-beta alumina (Na-beta) battery is a chemical storage technology with the potential to ultimately meet cost and performance targets for renewable integration and grid applications. ARPA-E supported a national lab - company partnership to investigate a planar geometry Na-Beta battery for grid-scale energy storage. As a continuation, with support from OE, the national lab partner is currently working on understanding and mitigating the battery degradation mechanisms, which will ultimately result in increased safety, longer cycle life, and reduced cost.

Zinc Halide Flow Battery: Zinc halide based rechargeable liquid flow batteries could produce substantially more energy at lower cost than conventional batteries for grid storage applications. Under OE-ARRA support, this technology is being incorporated into a pioneering 25 MW / 3hr facility to firm 50MW of wind for a California utility. If successful, this storage technology will be demonstrated as a cost-effective alternative to 50MW of new generating capacity. ARPA-E supported laboratory scale research on an advanced electrode with mixed-metal catalyst materials, as an alternative to traditional carbon electrodes, providing greater durability and decrease cost.

Wide-Bandgap Semiconductor Power Electronics: OE supports development and demonstration of wide bandgap (WBG) semiconductor devices based on materials such as Silicon Carbide (SiC) and Gallium Nitride (GaN). Modules specifically are targeted for grid-tied energy storage systems which result in high power density and better performance than silicon-based systems. ARPA-E supports development of WBG devices of increasing voltage, efficiency, integration and power handling capability, for electric power handling and management capabilities across a range of energy applications. This collaboration between OE and ARPA-E will enable more efficient storage management and control modules.

Through these related and integrated efforts on scientific research, technology development, demonstration and deployment, DOE is pursuing a coordinated agenda aimed at positioning the U.S. at the forefront of development of commercially relevant energy storage technology.

According to a recent GAO Report,[42] "DOE has taken steps to internally coordinate its battery and energy storage initiatives through activities that, among other things, defined common technology goals" (p.1) and "DOE has taken steps to internally coordinate its electric vehicle battery and electric grid storage initiatives through several actions. We found that these involved defining common technology goals; establishing strategies; and monitoring, evaluating, and reporting results. Specific steps… Established two working groups called integrated technical teams – Electric Vehicle Battery Technical Team and Grid Modernization Technical Team." (p.27)

External Collaboration

Importantly, DOE does not work in isolation from industrial organizations, other Federal and State agencies, and external stakeholders. Each Office maintains frequent and formal interactions with industry, academia, governments, regulatory bodies, and associations to ensure that priorities are re-calibrated and that resources are focused on the most urgent and impactful areas. This interaction with industry enables DOE to leverage its resources and expertise in advancing its overall mission to create a sustainable and commercially sound base of storage manufacturers and users.

Building and maintaining effective public–private partnerships is one of the key goals for achieving the objectives of the DOE's energy storage program. The strategy is to engage world-class professionals from key public and private organizations and help support and leverage research and development so that it meets the goals of DOE and the nation. Partners include electric utilities and manufacturers of energy storage devices, electricity consumers, project developers, and State and regional agencies.

[42] GAO, *Batteries and Energy Storage Federal Initiatives Supported Similar Technologies and Goals but Had Key Differences,* August 30, 2012.

Examples of electric utility stakeholders include investor-owned and public utilities; electric cooperatives; and Federally chartered entities such as the Tennessee Valley Authority, Bonneville Power Administration, and Western Area Power Administration. Partners also include the California Energy Commission and New York State Energy Research and Development Authority, who are partnering with major pioneering storage installations. DOE works closely with industry partners, and many of its projects (and all of its Recovery Act demonstrations projects) are cost-shared at a significant level. In the area of storage, DOE also works with national and regional interest groups, such as the Electricity Storage Association, National Rural Electric Cooperative Association (NRECA), National Alliance for Advanced Technology Batteries (NAATBaat), California Energy Storage Association (CESA), Texas Energy Storage Association (TESA), New York Battery Energy Storage Technology consortium (NYBEST), the storage association in Vermont, and the Pacific Northwest Economic Region – Energy Storage Coalition. DOE also has extensive collaboration with the National Electrical Manufacturers Association, and similar industry groups, in order to harmonize grid storage technology development and commercialization with appropriate industry standards and practices, both now and in the future.

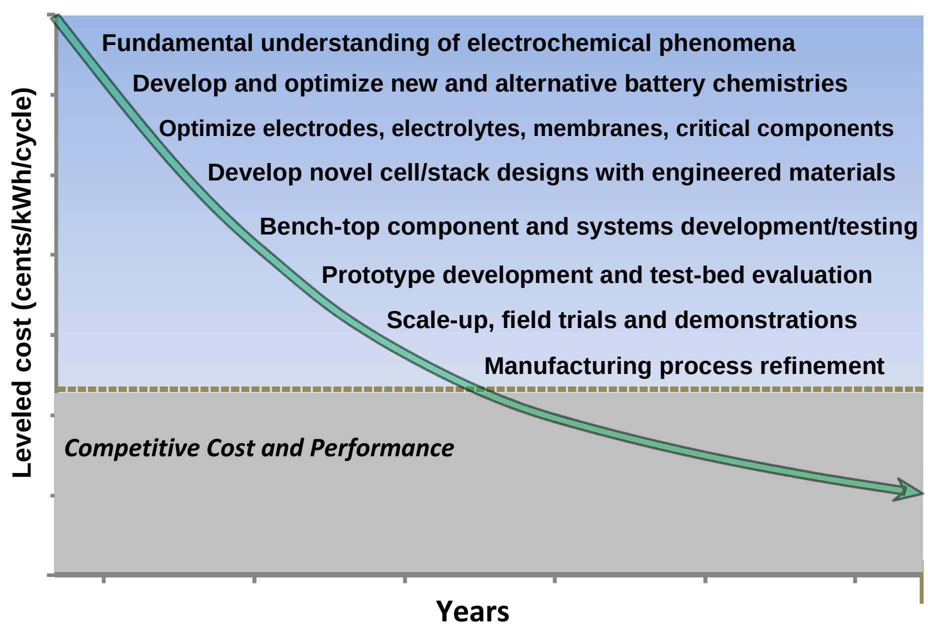
The engagement of public–private partnerships takes several forms:

- Technical exchanges achieved through periodic conferences, workshops, annual peer reviews, informal meetings, and joint R&D planning sessions in addition to the work being executed by the various National Laboratories.
- Communications and outreach through websites, webcasts, meetings, and publications in technical journals to foster information sharing and technology transfer.
- Cost-shared R&D projects that leverage resources and focus on accomplishing tasks of mutual interest. It also signals the willingness of the private parties in taking over and sponsoring the energy storage efforts beyond the limitations of government.
- Competitive solicitations to engage the nation’s top R&D performers in projects to design, fabricate, laboratory test, field test, and demonstrate new technologies, tools, and techniques.
- Small Business Innovative Research (SBIR) grants, which can be used by Federal agencies to nurture innovative concepts from small businesses.
- International collaborations- DOE participates in the International Energy Agency Annex on Energy Conservation through Energy Storage, and collaborative projects that complement DOE efforts (e.g., Korea – sodium sulfur battery development).
- Inter-agency collaborations—DOE works with resource and regulatory agencies under the Federal Inland Hydropower Working Group to provide input to the creation and piloting a two-year FERC licensing process for closed-loop pumped-storage projects as called for in Section 6 of the Hydropower Regulatory Efficiency Act of 2013.

7.0 Actions Specific to Technology Development

As noted earlier, technology development spans a range of activity, depending on the nature of the technology, its maturity (e.g., technology readiness level), and anticipated application environment. As pointed out by stakeholders in multiple workshops, the process of accelerating development, maturation and deployment of storage technologies requires research, development and demonstration tailored to the technologies. An illustrative display of technology development (nominally for a battery) is shown below.

Figure 9 -- Steps to Drive Down Cost in Technology Development



At all stages of technology development, improved scientific and engineering knowledge is vital for resolving critical cost and performance challenges as well as for feeding the creative processes for invention and innovation. Focused exploration of fundamental materials science, transport processes, and interface behavior relevant to energy storage contributes to the body of knowledge necessary for disruptive and evolutionary advances in energy storage technology.

In the strategy described above, there is an emphasis on advancements in research that can ensure long-term breakthroughs in cost and reliability, leading to a sufficient pipeline of future deployments. ***Applied material research***, enables the transition of scientific and engineering advances to specific challenges of critical components in energy storage devices. For the generalized battery development sequence depicted above, materials are modified with an understanding of electrochemical science and engineering fundamentals, e.g. current distribution, ion and electron transport, interfacial electron-transfer reactions, to enable greater energy density, higher current fluxes, slower dendrite growth, more conductive electrolytes, more effective separators, etc., enabling not only dramatic reductions in cost but also substantial improvements in device performance. Such advances are possible with many storage technologies, and development efforts are prioritized to components and concepts that will have the greatest impact on storage competitiveness, safety, lifetime, and other attributes, guided by detailed cost and performance models. One area of particular relevance is gaining a better understanding of degradation processes and mechanisms that affect the reliability of energy storage components. The ultimate goal is to effectively channel scientific advances and promising technologies towards commercialization.

In the area of ***device development***, the focus is on all the system components that comprise the AC energy storage system. The overall cost of energy storage systems can be roughly broken down to 25%-40% at the device level—i.e., where energy is held until needed, such as chemical/electrolytes in batteries, flywheels, etc.; and approximately 20% to 25% for associated power electronics—which ensure the proper and safe charge and discharge of stored energy; the remaining costs are associated with the balance of plant—i.e., facilities—as well as installation, engineering, and financing. Thus, R&D and demonstrations need to be undertaken in the development of design tools and electrochemical engineering for component and system tradeoff and optimization, as well as the development of new designs for components, subsystems, and systems. In this area we need targeted programs to reduce capital costs, at the device level.

Perhaps the greatest impact will come from ***system-level deployment***, since in situ testing and assessments can provide sufficient risk mitigation to further the adoption of storage by industry. DOE has undertaken a number of collaborative demonstrations with State and private partners. System-level deployments also include:

– Community and commercial establishments, university campuses, shopping centers, etc.
– Central station and distribution level
– Civilian and military microgrids
– Managing variability of renewable generation
– Isolated grids (Hawaii, Alaska, Texas, and islands)
– Grid services from EV/PHEV

The utility industry, as represented by the Electric Power Research Institute (EPRI)[43], has outlined use cases for demonstrations in the near future. Specifically the use cases involve: bulk energy storage systems (for renewable energy ramp control, resource adequacy, short-term balancing and reserves, etc.); distributed energy storage systems (for voltage regulation/reactive power support, peak load management, etc.); edge of grid energy storage systems (renewable integration, upgrade deferral, EV charging, back-up power); customer premise energy storage systems (electricity bill management, back-up reliability, renewable integration, upgrade deferral). A high priority is to have a demonstration focused on energy storage systems that can

[43] EPRI, *Grid Energy Storage: Challenges and Research Needs,* Draft White Paper, July 8, 2013

be deployed at electrical substations, in the 1-4 MW and the 3-4 hr size range. It will address the challenge of cost-effective deployment of such systems, providing multiple functions on the grid and provide multiple value streams to their owner/operators.

Demonstrations are vital contributors to both improving technology, but in tailoring to meet electric system requirements, and creating a body of experience that accelerates early adoption and supports resolution of institutional issues affecting deployment. DOE provided ARRA funding for extensive deployment activities. See Appendix B for a description of specific energy storage projects funded with ARRA resources—and co-funded by industry. However, new and improved storage technologies are moving through the development pipeline and it may be necessary for these technologies to undergo field trials and demonstrations in order to facilitate their advancement to equitable consideration for deployment. Field demonstrations can be leveraged to validate application performance and model results to achieve the energy storage objectives.

DOD power systems for bases, in particular in microgrid formats, serve as a particularly valuable test and demonstration environment for new technology.

Associated with system-level deployment is a focus on working with industry, at the pre-competitive stage, to promote advancements in manufacturing and use cases. As we think further about the widespread deployment of energy storage systems, we need to focus on the manufacturability of both devices and system components, since advancements in manufacturing will allow for cost reductions and greater reliability, as well as addressing the need for smarter sourcing of resources and recycling existing materials.

Emergency Preparedness

A more reliable, resilient, and secure power system is essential for the protection of critical infrastructure across regions. Microgrid systems combined with grid scale energy storage are being developed as a robust solution for increasing the resiliency of critical infrastructure. Grid scale energy storage, when combined with distributed renewable generation, would allow microgrids to provide reliable power for essential services over an extended time period of emergency. During non-emergency time periods the system can reduce demand charges for the user and provide compensated services to the grid.

DOE has already initiated work with the States and with DOD to implement a number of such resilient microgrid designs. To further develop this storage/microgrid concept, DOE is collaborating with State energy offices, regulators and the private sector to develop and promote grid scale energy storage with microgrids enhancing resiliency of critical infrastructure.

8.0 Goals and Actions Specific to Analysis

Quantitative analytics is a critical component of an integrated storage RD&D strategy. It provides valuable cost/performance targets of storage systems and components for sustained market competitiveness, and insights into the market design barriers and regulatory impediments. It informs and supports decision makers at DOE and other funding agencies in guiding the RD&D agenda toward setting near-term and long-term goals for market introduction and prudent growth potential in a changing electricity market place as other new clean technologies are competing for market adoption. Analytical methods are applied to both forward-looking explorations and studies that consider future grid operations, market rules and environmental constraints, as well as on demonstrations and evaluations of technology prototypes in many different real-world applications and locations to substantiate and validate cost-performance characteristics of today's technologies.

Analytics is also being utilized to develop new or enhance existing design and engineering tools to consider the specific characteristics of storage technologies. Analytics methods enhance the generation resource and transmission planning process such that energy storage can be employed on an equal level with generation expansion, transmission and distribution system upgrades rather than as an afterthought once new generation and transmission has been deployed. This requires the integration of analytics methods into existing planning, design, and sizing tools as well as the education of today's and tomorrow's engineers in using these advanced tools.

Furthermore, market conditioning activities are necessary for the market introduction of advanced storage technologies. Activities focus on the development of codes and standards to measure performance, assure the health and safety in the deployment of novel storage systems, and provide communications and control protocols for the integration into existing energy management control networks.

Specifically, quantitative analytics enables decision makers and the nascent storage industry to:

- Sharpen cost and performance targets for various stationary storage applications and different market designs, locations within the electricity infrastructures, and use-cases
- Develop and enhance storage component cost modeling to guide the R&D agenda and reveal cost-reduction pathways for the vendor community.
- Articulate the value proposition(s), and develop business cases to instill confidence in nascent technologies among investors, regulators, and utility decision makers
- Assess the impact of grid operational differences across the regions, as well as different market designs on energy storage size and controls requirements, and evaluate the role of storage in achieving a more resilient, reliable, cleaner energy infrastructure to increase the nation's energy security.
- Inform states and federal regulators and policy makers regarding the role of storage in grid operations, resource and transmission planning to meet the nation's needs for the 21st century.

- Develop or enhance planning, design and engineering tools to integrate storage into buildings, distribution, and transmission networks.
- Develop codes and standards rapidly to fill the gap of uniform procedures and guidelines necessary to wide-scale deployment and market acceptance.

To meet these outcomes above, the following targeted analyses and tool development activities are planned:

Component-cost modeling

DOE has already funded the initial development of a component cost model for redox flow batteries, fuel cells, Li-ion batteries, and other technologies to reveal the cost-reduction potential of individual components and the entire storage system and pathways to achieve cost/performance targets. Component-cost modeling would continue to capture cost improvement mechanisms by advancements in manufacturing, novel materials, and engineering designs. Component cost tools would be open-sourced and continually updated with new materials, engineering, and manufacturing approaches and for new electro-chemistries. This activity would benefit the vendor community, as well as inform DOE's program managers in adjusting the future RD&D agenda.

Electric Power System Analysis and Technical Support

To value the key system benefits of very fast and accurate response of energy storage technologies to grid operators' dispatch signals, a set of system analysis studies are envisioned that would specify new regulation reserve capacities that are science-based rather than rely on rule-of-thumb-based approaches. Additional analysis in collaborations with ISOs, and other grid operators would enable value-based treatment of reserve-assets.

Collaboration with States and Regions:

The recent California PUC ruling on storage targets for 2020 represents a unique opportunity for increasing market adoption of electricity storage in California specifically, and the United States in general. Analytical work targeted to support the large-scale deployment of storage in all phases of the deployment including siting, selection of applications, operations and maintenance, would increase the likelihood of storage technology to become an enduring grid asset with sustainable business models.

More broadly, collaboration with FERC, RTO, state agencies, grid operators, and utility entities provides technical support to identify the specific regional grid operational challenges based on existing environmental constraints and future contributions from renewable energy resources.

Analysis of Demonstration Projects

Analytical studies would evaluate cost-effectiveness of high-value demonstrations to validate device performance and overall grid benefits. This activity would utilize the lessons-learned from the ARRA storage demonstrations and selected other applications of high value for the industry to solidify the expected performance and to create confidence in the investment and utility and grid operator communities. It is expected that this activity would be enduring along-side technology R&D program elements under various DOE funding mechanisms. This analytics element lends itself to cost-sharing with local and regional stakeholders.

Planning tools development

Today's engineering planning and design tools lack the ability to size, design, and validate the proper functioning of distribution system and transmission system operations with energy storage included in the mix of grid assets. It is unlikely that this gap in the tool-sets of grid planners would be filled by industry, particularly, not in time for the early market adoption phase in the next 3-5 years. Therefore, it is crucial for the DOE to provide the necessary analytical resources to develop new or enhance existing tools in collaboration with software developers and the planning communities. In particular, there is a need in both distribution and transmission planning tools to explore scenarios that maximize the utility of grid assets for multiple services. This requires complex co-optimizations of several objectives to be considered. If successfully implemented services and locations can be identified that allow utility and grid planners to find optimal locations and optimal control strategies that maximize the total value of storage.

Market acceptance

This activity consists of codes and standards development engagements and outreach activities to regulators and market designers. This activity is envisioned to be an enduring component in the entire DOE near-term and long-term strategy. New technology development gaps in the existing codes and standards landscape across national and international standards may need to be evaluated to identify potential impediments of existing rules that would provide market entry barriers for novel designs and applications of energy storage.

9.0 Energy Storage Technology Standardization

As the energy storage field is developing a level of maturity and performance to the storage community and users, standardization is becoming paramount. A number of ongoing DOE activities already support this:

- The **DOE International Energy Storage Database, (IESDB)**[44] is the first freely accessible database of energy storage installations and related state and federal legislation/policies. It is an online tool designed to be accessible to a wide variety of stakeholders and has tremendous potential to help grow the energy storage industry. The IESDB is quickly becoming the go-to source for energy storage project and policy information.

- The **DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA**[45] is a how-to guide for utility and rural cooperative engineers, planners, and decision-makers to plan and implement electricity storage projects. Additionally, the handbook is an information resource for investors and venture capitalists on the latest developments in technologies and tools to guide their evaluations of electricity storage opportunities. It builds upon the *EPRI-DOE Handbook of Energy Storage for Transmission and Distribution Applications*, released in December 2003. It includes a comprehensive database of the cost of electricity storage systems in a wide variety of popular electric utility and customer applications, along with interconnection and integration schematics. A list of significant past and present electricity storage projects is also included for a practical perspective.

- **SNL Energy Storage Test Pad** provides third party cell-to-module-to-system validation of commercial and research scale storage solutions with a focus on grid scale applications. The lab and its staff provide engineering consultation on determining the most appropriate testing and applications for a given technology, performance and safety evaluation of the technology and systems, and provide public reporting of results for use by vendors, potential investors and customers.

- **Development of a protocol to measure and report performance of energy storage technology,** SNL is actively developing and distributing protocols for the energy storage community to provide uniform best practices for measuring, quantifying, and reporting the performance, reliability, applications and safety of energy storage systems.

Bibliography

Akhil, A.A., Huff, G, Currier, A.B., Kaun, B.C, Rastler, D.M., Chen, S.B., … , Gauntlett, W.D. (2013). DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA. *Sandia National Laboratories Report,SAND2013-5131*. Retrieved from: http://www.sandia.gov/ess/publications/SAND2013-5131.pdf.

[44] Available at: http://www.energystorageexchange.org/
[45] Available at: http://www.sandia.gov/ess/publications/SAND2013-5131.pdf

Auer, J. & Keil, J. *State-of-the-art electricity storage systems: Indispensable elements of the energy revolution.* [Powerpoint slides]. Retrieved from: http://www.dbresearch.com/PROD/DBR_INTERNET_EN-PROD/PROD0000000000286166/State-of-the-%20art+electricity+storage+systems%3A+Indispensable+elements+of+the+energy+r%20evolution.pdf.

California Energy Commission. 2020 Strategic Analysis Of Energy Storage In California. Retrieved from: http://www.law.berkeley.edu/files/bccj/CEC-500-2011-047.pdf.

Carnes, Kelly H. *Walking the Walk: DOD's Role in Accelerating Renewable Energy Technology Development* [Powerpoint slides]. Retrieved from: http://e2s2.ndia.org/schedule/Documents/Abstracts/12669.pdf.

Denholm, P.; Fernandez, S.J.; Hall, D.G.; Mai, T.; Tegen, S. (2012). "Energy Storage Technologies,"
Chapter 12. National Renewable Energy Laboratory. Renewable Electricity Futures Study, Vol. 2, Golden,
CO: National Renewable Energy Laboratory; pp. 12-1 – 12-42.
DOE International Energy Storage Database (beta). (2013). Policies. Retrieved from: http://www.energystorageexchange.org/policies.

DOE International Energy Storage Database (beta). (2013). *Projects*. Retrieved from: http://www.energystorageexchange.org/projects.

Doetsch, Christian. *Future Energy Storage/Balancing Demand* [Powerpoint slides]. Retrieved from: http://www.oeko.de/files/aktuelles/application/pdf/20120913_panel4_doetsch.pdf.

---- "Energy Storage Market Outlook H1 2013: A New Awakening." *Bloomberg New Energy Finance* 28 June 2013: 1-31. *New Energy Finance.* Web. 28 Jul. 2013.

Eyer, J., & Corey, G. (2010). Energy storage for the electricity grid: Benefits and market potential assessment guide. *Sandia National Laboratories Report, SAND2010-0815*, Albuquerque, New Mexico.

Hauer, A. *Energy Conservation Through Energy Storage Program* [Powerpoint slides]. Retrieved from: http://www.iea-eces.org/files/090525_broschuere_eces.pdf.

IEA- Energy Conservation through Energy Storage. *Annual Report 2012*. Retrieved from: http://www.iea-eces.org/files/annualreport_2012_1.pdf.

Lott, M.C., Kim, S.-I., Tam, C., & Elzinga, D. (2013). Technology Roadmap: Energy Storage. *Forthcoming IEA Working Paper, draft July 19th 2013.*

Narayanan, S. R., Prakash, G. K., Manohar, A., Yang, B., Malkhandi, S., & Kindler, A. (2012). Materials challenges and technical approaches for realizing inexpensive and robust iron–air batteries for large-scale energy storage. *Solid State Ionics*, *216*, 105-109.

Nicholson, M. & Stepp, M (2012). "Lean, Mean, and Clean II: Assessing DOD Investments in Clean Energy Innovation." *The Information Technology & Innovation Foundation*. Retrieved from: http://www2.itif.org/2012-lean-mean-clean-dod-energy.pdf.

Rastler, D. M. (2010). *Electricity energy storage technology options: a white paper primer on applications, costs and benefits*. Electric Power Research Institute.

Rastler, D., Schainker, R., Kaun, B., Steeley, W., & Kamath, H. (2013). Grid Energy Storage: Challenges and Research Needs. *Forthcoming EPRI White Paper, Revision 7.*

SERDP-ESTCP Press Release. *DoD Study Finds 7,000 Megawatts of Solar Energy Potential on DoD Installations in Mojave Desert.* January 13th, 2013. Retrieved from: http://www.serdp.org/News-and-Events/News-Announcements/Program-News/DoD-study-finds-7-000-megawatts-of-solar-energy-potential-on-DoD-installations-in-Mojave-Desert.

Teller, O., Nicolai, J.P, Lafoz, M., Laing, D., Tamme, R., Pedersen, A.S, … , Clerens, P. Joint EASE/EERA recommendations for a European Energy Storage Technology Development Roadmap towards 2030. *European Association for Storage of Energy.* Retrieved from: http://www.ease-storage.eu/tl_files/ease-documents/Stakeholders/ES%20Roadmap%202030/EASE-EERA%20ES%20Tech%20Dev%20Roadmap%202030%20Final%202013.03.11.pdf.

Turner, Guy. *Global Renewable Energy Market Outlook 2013 Fact Pack* [Powerpoint slides]. Retrieved from: http://about.bnef.com/fact-packs/global-renewable-energy-market-outlook-2013-fact-pack/.

US Government Accountability Office. *Batteries And Energy Storage: Federal Initiatives Supported Similar Technologies And Goals But Had Key Differences.* August 30, 2012. Retrieved from: http://www.gao.gov/assets/650/647742.pdf.

Wesoff, Eric (2013). *Primus Lands DOD Contract for Energy Storage at Marine Base Microgrid.* Retrieved from: http://www.GreentechMedia.com

Yang, Z., Zhang, J., Kintner-Meyer, M. C., Lu, X., Choi, D., Lemmon, J. P., & Liu, J. (2011). Electrochemical energy storage for green grid. *Chemical Reviews*, *111*(5), 3577-3613.

Appendix A: Short Description of DOE Office Programs on Storage

Office of Science

Office of Science, Basic Energy Sciences

The key research areas to realize advanced storage technologies for the future were identified in the SC-BES workshop on Basic Research Needs for Electrical Energy Storage (April 2007). DOE technology offices that participated in this workshop include Electricity Delivery and Energy Reliability (OE) for utility-scale energy storage and Energy Efficiency and Renewable Energy (EERE) for their Vehicle Technologies program. A number of specific areas of fundamental research for both batteries and electrochemical capacitors are outlined in the associated workshop report *Basic Research Needs for Electrical Energy Storage* (http://science.energy.gov/~/media/bes/pdf/reports/files/ees_rpt.pdf). These include: (1) Novel designs and strategies for chemical energy storage, (2) Solid-electrolyte interfaces and interphases, (3) Capacitive energy storage materials by design, (4) Electrolyte interactions in capacitive energy storage, (5) Multifunctional materials for pseudocapacitors and hybrid devices, and (6) Theory and modeling.

Core Research

SC-BES funds approximately $7.5M/yr in research projects from the "core" single investigator and small group research program that, while fundamental in nature, address aspects of these scientific issues and are topically connected to electrical energy storage. In addition, SC-BES has made major investments that support energy storage research in the Energy Frontier Research Center (EFRC) program and the Batteries and Energy Storage Hub.

Energy Frontier Research Centers

In FY2009, SC-BES significantly increased the investment in fundamental energy storage research with the initiation of six EFRCs directly related to electrochemical energy storage (these EFRCs have a five-year budget of $90M). EFRC research is addressing the priority research directions outlined in the workshop report and includes investigations of interfacial properties and chemistry, development of high-performance nanostructured materials, understanding the role of electrolyte chemistry, discovery of novel electrocatalysts, and enhancing ion and electron transport properties and dynamics.

In addition, research in a number of cross-cutting EFRCs, while not directly underpinning batteries or capacitors, is addressing fundamental science that would propel electrical energy storage advancements (synopses of all 46 EFRCs can be found at http://science.energy.gov/bes/efrc/). Ongoing coordination activities with the DOE technology offices maintain awareness across DOE of the directions and outcomes of these research programs.

Energy Innovation Hub – Batteries and Energy Storage

In FY 2013, SC-BES announced the selection of the Joint Center for Energy Storage Research (JCESR), led by Argonne National Laboratory, for the Batteries and Energy Storage Hub. As defined in the funding opportunity announcement, the Batteries and Energy Storage Hub addresses the scientific and engineering research needed to advance the next generation of electrochemical energy storage for both transportation and the grid. The JCESR team brings together leading experts in both transportation and grid storage research to focus on the scientific barriers for electrochemical energy storage for both of these applications. JCESR benefits from co-location of major research activities funded by EERE, OE, and ARPA-E, facilitating the evolution of synergies among the programs and ensuring continued delineation of the energy storage research activities across DOE.

JCESR has launched a research program to perform underpinning science with the goal of developing research prototypes for electrochemical energy storage systems beyond lithium-ion for the grid and transportation. The research emphasizes discovery of new energy storage chemistries through the development of an atomic-level understanding of reaction pathways and development of universal design rules for electrolyte function. The overarching goals driving the scientific and engineering research towards next generation energy storage technologies are summarized by JCESR as “5/5/5”: five times the energy density of today’s systems at one-fifth the cost within five years, the award period for the Hub.

Federal management of the Hub is led by SC-BES in close coordination with EERE and ARPA-E for the initial selection review and for ongoing assessments of the Hub R&D activities. More information on JCESR can be found at http://www.jcesr.org/ and more information on Energy Innovation Hubs in general can be found at http://energy.gov/science-innovation/innovation/hubs

Energy Efficiency and Renewable Energy (EERE)

Energy Efficiency and Renewable Energy – Investments in Energy Storage

The Energy Efficiency and Renewable Energy Office is accelerating the research, development, demonstration, and deployment of new and advanced energy storage technologies that can be used in buildings, electric vehicles, or to help address the added variability and uncertainty of variable renewable technologies. Currently most of the work is concentrated in Sustainable Transportation and Renewable Power generation such as pumped hydro storage.

The Sustainable Transportation programs focus on reducing the cost, volume, and weight of batteries, while simultaneously improving the batteries' performance (power, energy, and durability) and ability to tolerate abuse conditions. Reaching the Office's goals in these areas and commercializing advanced energy storage technologies might allow more people to purchase and use electric drive vehicles.

- Exploratory Battery Materials Research: Addresses fundamental issues of materials and electrotechnical interactions associated with lithium ion and beyond lithium batteries. The research attempts to develop new and promising materials, use advanced material models to predict the modes in which batteries fail, and employ scientific diagnostic tools and techniques to gain insight into why materials and systems fail.
- Applied Battery Research: Focuses on optimizing next generation, high-energy lithium ion electrochemistries that incorporate new battery materials. This activity emphasizes identifying, diagnosing, and mitigating issues that negatively impact the performance and life of cells using advanced materials.
- Advanced Battery Development, Systems Analysis, and Testing: Focuses on the development of robust battery cells and modules to significantly reduce battery cost, increase life, and improve performance. This research aims to ensure these systems meet specific goals for particular vehicle applications.

The Renewable Power programs focus on using energy storage to address the variability and uncertainty of solar and wind and provide greater power system flexibility. This includes energy storage devices developed in concert with renewable power sources such as concentrating solar power or hydropower technologies. The Renewable Power programs focus in the following areas.

- Research and Development: This research investigates the development of new materials and systems such as the enhancement of thermal and thermochemical energy storage systems for concentrating solar power plants with the goal of driving cost and performance toward the SunShot targets.

- Testing and Field Demonstrations: This includes projects that investigate the efficacy and value of energy storage in addressing issues such as variability and load shifting using technologies such as electrochemical storage or advanced pumped storage hydro plants.
- Modeling and Analysis**:** These efforts investigate the cost and benefits associated with using energy storage to enable the use of more renewable energy technologies in the electricity system. These include system wide studies in areas like Hawaii in the Hawaii Solar Integration Study, the West in the Western Wind and Solar Integration Study, and the United States in the Renewable Energy Futures Study and the SunShot Vision Study. This also includes an analysis of the emissions and economic benefits of hydrogen generation from wind power plants for use in fuel cells. . Additionally, these efforts work to improve modeling capabilities as they relate to new technologies such as variable speed pumped hydro storage.

Advanced Research Projects Agency – Energy (ARPA-E)

GRIDS

ARPA-E's Grid-Scale Rampable Intermittent Dispatchable Storage (GRIDS) program focuses on development of low-cost storage technologies for the electric grid. Specifically, GRIDS technologies are designed to address the challenge of renewable ramping. Initiated in 2010, ARPA-E's GRIDS program is developing new storage technologies with a capital cost of less than $100 per kilowatt-hour that can scale to store megawatt-hours of electricity and be used at any location on the grid. The program includes 12 projects in a variety of technologies. A few of these are in conjunction with OE ARRA projects.

HEATS

ARPA-E's High Energy Advanced Thermal Storage (HEATS) program seeks to develop revolutionary, cost-effective ways to store thermal energy. Thermal energy--or heat energy--is involved in over 90% of all energy technologies, and there is a critical need to find efficient, cost-effective ways to store it. Initiated in 2010, the HEATS program includes 6 projects.

SBIR/STTR 2012

In 2012, ARPA-E funded a Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) program that included four energy storage projects focused on developing low-cost energy storage devices for use on the customer side of the meter. Low-cost storage located "behind the meter" can convert intermittent distributed generation assets into reliable low-cost power, as well as helping to shave peak loads on the centralized grid. ARPA-E's SBIR/STTR program funded development of systems with peak power of 2.5 kW and duration of 4 hours with a footprint equivalent to that of an appliance (such as a refrigerator) that could be deployed in homes and small businesses as distributed energy storage resources.

ADEPT

ARPA-E's ADEPT program, short for "Agile Delivery of Electrical Power Technology," includes 14 projects in advanced power conversion technologies: circuits, transistors, inductors, transformers, and capacitors. Around 30% of the electricity used in the U.S. today flows through power converters, and a significant amount of energy is lost when that electricity is modified to a different current or voltage. That's because most power converters are based on decades-old technology and rely on expensive, bulky, and failure-prone components. The DOE estimates that in 20 years, 80% of the electricity used in the U.S. will flow through power converters, so there is a critical need to improve their efficiency. Initiated in 2010, the ADEPT program funds aim to develop advanced power conversion technologies that, if successful, would increase energy efficiency, improve the performance of electrical devices, and accelerate growth of the smart grid. ADEPT program innovations also could help establish U.S. businesses as technical leaders in power electronics, and bring lower power bills and less expensive electronics to American consumers.

SWITCHES

ARPA-E is currently seeking proposals for its SWITCHES program, short for "Strategies for Wide-Bandgap, Inexpensive Transistors for Controlling High Efficiency Systems." Initiated in 2013, this program seeks to fund transformational advances in wide bandgap (WBG) materials, device fabrication, and device architectures. The goal of the SWITCHES program is to enable the development of high voltage (1200V+), high current (100A) single die power semiconductor devices that, upon ultimately reaching scale, would have the potential to reach functional cost parity with silicon power transistors while also offering breakthrough relative circuit performance (low losses, high switching frequencies, and high temperature operation). If successfully developed, these transformational technologies could reduce the barriers to ubiquitous deployment of low-loss WBG power semiconductor devices in stationary and transportation energy applications. SWITCHES technologies can increase energy efficiency, improve the performance of electrical devices, and accelerate growth of the smart grid.

Other Grid Storage Projects

ARPA-E funded the development of a number of grid storage technologies, including novel batteries and flow batteries, as part of its open solicitations in 2009 and 2012. Projects include work on sodium beta batteries, iron flow batteries, potassium and sodium based systems.

Office of Electricity Delivery and Energy Reliability

Office of Electricity Delivery and Energy Reliability – Energy Storage Program

The Energy Storage Program is focused on accelerating the development, demonstration and deployment of new and advanced energy storage technologies that will enhance the stability, reliability, resilience and economics of the future electric grid, which includes substantial contribution of intermittent renewable energy resources such as wind and solar power generation. The Energy Storage Program addresses three key challenges that are currently limiting widespread adoption of energy storage technologies.

- **Improving the cost/benefit ratio** of energy storage through advancements in materials engineering and device architectures;
- **Field Validation** of first-of-a-kind systems in representative utility environments to optimize storage devices for diverse utility applications and gain experience with the performance and behavior of diverse storage technologies;
- **Modeling and Analysis of Storage Systems** to assess the use, costs and benefits of energy storage, identify institutional and policy barriers, and develop tools for utilities and users planning to introduce and use energy storage.

To address these challenges, OE supports work by Universities, National Laboratories and Industry focused on four areas including:

- **Storage System R&D –** Addressing critical technical and economic limitations of state of the art energy storage technologies, and exploring new technologies that promise major advances in cost, performance, cycle life, and safety. Technologies primarily include mechanical (e.g. flywheels) and electrochemical (advanced redox flow, sodium, lithium, lead-acid, and novel derivatives and variations) batteries. Targeted material science and engineering R&D is conducted in order to maximize the durability, reliability and performance of the storage system while minimizing the installed capital cost.
- **Power Conversion and Grid Integration –** Addressing the unique power conversion needs for effective delivery of power to and from energy storage systems to enable maximum utilization of energy storage for a myriad of grid applications. Technical efforts focus on new power electronic components and converter architectures that reduce cost, improve performance, and extend life of power converters for energy storage.
- **Testing and Field Demonstrations –** Collaborating with manufacturers, States, municipalities, and utilities, in cost-shared testing and field demonstrations to establish operational performance of energy storage systems in real world conditions. These efforts focus on understanding and analyzing the benefits of deploying and utilizing energy storage to serve a wide range of application from: frequency regulation, load following, power quality enhancement, voltage and VAR support, load shifting, grid congestion relief, arbitrage, and many others. Siting issues, control strategies, integration with grid

operations, maintenance, storage performance, as well as beneficial grid impacts are just a few issues uniquely addressed by field demonstrations. OE has responsibility for reporting on technical performance of ARRA-funded storage demonstration projects.

- **Analytic Studies** - Developing analytic tools of storage system, device, and component control and performance, storage cost models, new industry standards, value stream determination, and studies of market economics, and deployment and grid integration challenges, serves to inform stakeholders and guide R&D investments.

SBIR - OE participates in SBIR on an annual basis with a storage topic jointly managed with SC-BES. Projects involve advanced work on electrodes, electrolytes, and membranes.

ARRA - OE manages the ARRA program of Energy Storage Demonstrations. The program includes 16 projects representing Large Energy Storage for Renewable Integration, Frequency Regulation, Distributed Storage for Grid Support, Compressed Air, and Demonstration of Promising Storage Technologies. Federal Funding $185M for these projects has attracted a cost-share of $585M. In addition, OE also manages 7 ARRA Smart Grid projects involving application of energy storage.

Other Federal Agencies – Energy Storage R&D Activities

While DOE provided the largest amount of funding for energy storage research, several other agencies also had initiatives that examined Batteries and energy storage topics. Table A1 shows the net funding obligations of other federal agencies:

Table A1[46]: Agency Battery and Energy Storage Initiatives and Funding Obligations, Fiscal Years 2009 through 2012 Agency

Agency	Number of initiatives	Funding obligations
DOE	11	$851,994,808
DOD	14	$430,274,229
NASA	8	$20,811,374
NSF	4	$8,582,868
EPA	1	$3,258,029
NIST	1	$1,375,000
Total	**39**	**$1,316,296,308**

The following describes the initiatives that are relevant to grid-connected storage deployment for each agency.

Department of Defense

DOD has been making large investments in storage research each year, devoting roughly $145 million per year since 2009, representing between 21% and 28% of the electricity research budget. There are currently programs being run by each branch of the military, as well as jointly with other organizations (e.g., ESTCP/SERDP). Currently, the DOD is running several microgrid scale energy storage projects involving battery technology coupled with renewable and locally fired natural gas plants. These tests each focus on different technology aspects, battery types and chemistries, and battery size (large batteries versus distributed assets. Projects are focused on improving microgrid self-sufficiency (islanding) by improving load management and generation efficiency through the addition of energy storage. Programs in various stages of completion exist at Forts Hickam and Devens (in collaboration with DOE), Sill, Oklahoma; Marine Corps Air Station Miramar, California; 29 Palms, California; Portsmouth Naval Shipyard, Maine; Fort Bragg, North Carolina; and Fort Detrick, Maryland

[46] Source: GAO-12-842, Batteries and Energy Storage

In addition to the microgrid-level programs, several ongoing energy storage projects that could impact grid-level technologies:

- The Installation Energy Test Bed at the Marine Corps Air Station in Miramar currently testing new energy technology including battery technology (see microgrid discussion)
- Los Angeles Air Force Base is optimizing tool and implementation hardware for the strategic charging of their fleet of plug-in electric vehicles.
- DOD also determined that their bases have potential for 7 GW of Solar Energy generation; fully harnessing this potential would require significant amounts of energy storage capabilities
- US Army Corp of Engineers Engineer Research & Development Center (ERDC) is part of the ESTCP program (associate with SERDP-ESTCP) that advances energy storage technologies
- Naval Surface Warfare Center Crane Division has a joint program with Purdue University that grants a master's degree in chemical engineering for work on energy storage, and is conducting significant research into energy storage
- There are several organizations under the Army's Research, Development, & Engineering Command (RDECOM) that have energy research ongoing:
  - The Tank, Automotive Research Development Engineering Center (TARDEC) has several programs researching battery life and performance, information that may be applicable for distributed deployment performance and optimization
  - US Army Armament Research, Development & Engineering Center (ARDEC) currently has a partnership with Sandia National Laboratory and the DOE Energy Storage Program; some of the joint efforts most recent breakthroughs involves better power electronics and power switches (thyristors)
  - US Army Communications-Electronics Research, Development & Engineering Center (CERDEC) has been involved in a microgrid effort to provide a secure electricity grid at the Fort Belvoir 300 Area Compound site. This effort is done under the umbrella of the Energy Working Group (EWG), a joint effort between the DOD and DOE
  - The Aviation & Missile Research, Development, and Engineering Center (AMRDEC), the Army Research Laboratory (ARL), and CERDEC have a joint program for collecting and storing solar power to provide continuous energy to company-level force protection systems in theater; the device relies on six rechargeable batteries
  - The US Army Natick Soldier Research, Development, & Engineering Center (NSRDEC) has worked on improving lightweight and portable energy generation and storage systems (mostly and solar/wind combined with batteries) that can be deployed by soldiers in forward operations

– The Army Research Laboratory (ARL) is carrying out both basic and applied research on energy storage, especially focused on nano composites for ultra-lightweight multifunctional structural-energy storage systems

National Science Foundation

The National Science Foundation (NSF) has several initiatives (e.g., FREEDM and CURENT Engineering Research Centers, the GOALI Program) in place to support the development of batteries and associated technologies. The following programs are active:

- Energy for Sustainability[47] – a program providing funding for fundamental research and education that will enable innovative processes for the sustainable production of electricity and transportation fuels. One of several interest areas includes advanced batteries for transportation which targets high-energy density and high-power density batteries suitable for transportation.
- Energy, Power and Adaptive Systems (EPAS)[48] - a funding program for projects focusing on electric power networks and grids, including generation, transmission and integration of renewable, sustainable and distributed energy systems; high power electronics and drives.
- Sustainable Energy Pathways[49] – a funding program for innovative and interdisciplinary basic research in science, engineering and education by teams of researchers for developing systems approaches to sustainable energy pathways. One of the topic areas is sustainable energy storage solutions.
- Renewable Energy Storage (RESTOR)[50] - Funding program through the Emerging Frontiers in Research and Innovation (EFRI) which awarded four grants on energy storage in 2010. Funded projects included a nanostructured capacitor, thermochemical routes to solar fuel production, novel compressed air storage for offshore wind energy storage and a regenerative hydrogen-bromine fuel cell system for energy storage.

[47] National Science Foundation, "Energy for Sustainability," https://www.nsf.gov/funding/pgm_summ.jsp?pims_id=501026, accessed July 2013
[48] National Science Foundation, "Energy, Power, and Adaptive Systems (EPAS)," http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=13380, accessed July 2013
[49] National Science Foundation, "Sustainable Energy Pathways (SEP)," http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=504690, accessed July 2013
[50] National Science Foundation, "ENG/EFRI FY2010 Awards Announcement," http://www.nsf.gov/eng/efri/fy10awards_RESTOR.jsp, accessed July 2013

Appendix B - ARRA Energy Storage Demonstration Projects

ARRA Energy Storage Demonstration Projects		
Project Title	**Project Description**	**Project Status (As of August. 2013)**
1. BATTERY STORAGE FOR UTILITY LOAD SHIFTING OR FOR WIND FARM DIURNAL OPERATIONS AND RAMPING CONTROL		
Duke Energy Business Services Notrees Wind Storage (LEAD-ACID BATT.)	36MW/24MWh Xtreme Power advanced lead acid battery for Wind Farm storage for frequency regulation as the targeted service.	The installation is complete and the system was in service since December of 2012.
Primus Power Corporation Wind Firming EnergyFarm (ZINC-BROMINE FLOW BATT.)	25MW/75MWh zinc bromine flow battery system for wind firming in Modesto Irrigation District.	The battery system design is still taking place. System planned to be service by Jan of 2015
Southern California Edison Tehachapi Wind Energy Storage Project (LITHIUM-ION BATT.)	8MW (32 MWh) Li-ion battery at substation within Tehachapi Wind Resource Area for voltage support, wind integration, frequency regulation, arbitrage.	The battery manufacturer and the developer are in process of designing the system. System planned for service in Feb of 2015
2. FREQUENCY REGULATION ANCILLARY SERVICES		
Hazle Spindle LLC. (Beacon Power) 20 MW Flywheel Frequency Regulation Plant (FLYWHEELS)	20MW (200 x 100KW) flywheels for frequency regulation in PJM.	Construction is still under way. Majority of equipment and material orders have been placed. GC has been selected for site construction. System is scheduled to be in service by Sepember 2015.
3. DISTRIBUTED ENERGY STORAGE FOR GRID SUPPORT		
City of Painesville Vanadium Redox Battery Demonstration Program (VANADIUM-REDOX FLOW)	Demonstration: 1 MW/8MWh vanadium redox flow battery (from Ashlawn Energy) for load following for Painesville Municipal Power station.	Essentially all R&D has been completed. Battery building construction complete. System planned for service in Oct of 2015.
Detroit Edison Company Advanced Implementation of Energy Storage Technologies (LITHIUM-ION)	S&C Electric, 18 CES units DowKokam Li-ion batteries + 2 CES units secondary use EV batteries Li-ion Bosch Batteries (total 20 units @ 25kW/50kWh each of 500kW/1MWh) for distribution side service providing aux. power for increase service reliability and quality.	Field operation testing has begun. System in service from July 2013.
East Penn Manufacturing Co. Grid-Scale Energy Storage Demonstration Using UltraBattery Technology (ULTRA-CAPACITOR/LEAD-ACID)	3MW East Penn UltraBattery (ultra-capacitor/lead-acid) providing frequency regulation services.	20,000 kWh frequency regulation delivered to PJM in June 2012.
Premium Power Distributed Energy Storage System (ZINC-BROMINE FLOW BATTERY)	1 MW Premium Power zinc bromide flow battery.	Energy storage system architecture, implementation, and coordination are still in process. System planned to be in service by Oct of 2014.
Public Service Company of New Mexico PV Plus Battery for Simultaneous Voltage Smoothing and Peak Shifting (LEAD-ACID BATTERY)	750KW/2.8MWh advanced lead acid battery for voltage smoothing and PV firming on PNM distribution feeder. (Battery by East Penn Manufacturing).	1.5 years into a 2-year demo. Executing various test plans for smoothing, shaving, and firming. System planned for service in Apr of 2014.
4. COMPRESSED AIR ENERGY STORAGE (CAES)		
New York State Electric & Gas Corporation Advanced CAES Demonstration 150 MW Plant Using an Existing Salt Cavern	150MW compressed air energy storage system for bulk energy storage. Project has been terminated.	Recipient requested termination after phase 1 feasibility study. Termination was effective Nov 2012.
Pacific Gas and Electric Company Advanced Underground Compressed Air Energy Storage	Advanced Underground CAES Demonstration Project Using a Saline Porous Rock Formation as the Storage Reservoir. 300MW CAES.	Completed Core Drilling and Extraction. Cores are currently undergoing Lab Analysis. System planned for service in March of 2023.
5. DEMONSTRATIONS OF PROMISING ENERGY STORAGE TECHNOLOGIES		
Aquion Energy Sodium-Ion Battery for Grid-level Applications (SODIUM ION BATTERY)	Aquion Energy's 10-15 kWh prototype sodium ion battery at Aquion's facility (non-grid tied)	Project completed in 2nd quarter of 2012.
Amber Kinetics, Inc. Flywheel Energy Storage Demonstration (FLYWHEELS)	Demonstration of a Flywheel System for Low Cost, Bulk Energy Storage 20KW (2 x 10kW) flywheels storing 80kWh energy in a pilot demo for demand management in SDG&E territory.	Beginning phase 2 scale-up for grid-tied demo with commercial. Planned for service in December of 2014.
Ktech Corp Flow Battery Solution for Smart Grid Renewable Energy Applications (CHROMIUM FLOW BATTERY)	250kW/1MWh EnerVault Iron Chromium flow battery for firming PV.	Installation is nearly complete and system planned for service in Oct of 2013.
Seeo Inc Solid State Batteries for Grid-Scale Energy Storage (SOLID-STATE ELECTROLYTE LITHIUM-ION)	~25kWhr Seeo prototype in conjunction with solar PV.	Prototype battery pack designed and the system to be in service by Jul of 2014.
SustainX Inc Isothermal Compressed Air Energy Storage (COMPRESSED AIR ENERGY STORAGE)	1.5MW/1MWh non-grid-tied above-ground isothermal compressed air energy storage (CAES) pilot system.	Fabricating/assembling full-scale pilot ICAES system for 9 month pilot test (non-grid-tied). System commissioning planned for November of 2013.

ARRA Smart Grid Demonstration Projects with Storage

Project Title	Project Description	Project Status (As of August. 2013)
Battelle Memorial Institute Pacific Northwest Smart Grid Demonstration Project. (LITHIUM-ION, LEAD-ACID, ZINC BROMINE FLOW BATTERY)	5MW/1.25MWh EnerDel Li-ion battery for high-reliability zone/microgrid support to be located in Salem, OR.	The large lithium-ion battery energy storage unit is installed and in service since May 2013.
	42kW/170kWh Demand Energy Networks advanced lead acid batteries (4 x 10kW/40kWh units + 2 x 1kW/5kWh units) for peak load management, demand response, and renewables firming	The system in service since March 2013.
	125kW/125kWh ZBB zinc bromine flow battery peak load, demand response, and renewables firming	The system in service since March 2013.
AEP Ohio gridSMARTSM Demonstration Project (LITHIUM ION BATTERY)	100kW/100kWh (4 units @ 25kW each) S&C Electric PureWave Li-ion batteries for Community Energy Storage.	4 battery units are being tested in a testing facility. Planned to be in service by January 2015.
Center for Commercialization of Electric Technologies (CCET) Technology Solutions for Wind Integration (LITHIUM-ION BATTERY	1MW/1MWh Xtreme/Samsung Li-ion battery for wind integration with Texas Tech and the South Plains Electric Coop.	The battery is delivered and is in process of installation. The system will be in service by December 2013.
Consolidated Edison Company of New York, Inc. Secure Interoperable Open Smart Grid Demonstration (LITHIUM PHOSPHATE BATTERY)	Battery storage at 7 locations, lithium phosphate, capacity range is 25-200kWh, 40-500kW maximum output.	Three units have been installed and in service from May 2013.
Southern California Edison Irvine Smart Grid Demonstration (LITHIUM-ION BATTERY)	17 homes with Residential Energy Storage Units (4kW/10kWh LG Chem Li-ion battery)	Residential Energy Storage Units, electric vehicle chargers, rooftop solar panels, and an assortment of Home Area Network devices within the 22 project homes are installed. The storage systems are in service from July 2013.
	9 homes will share a community energy storage unit (25kW/50kWh battery)	Community Energy Storage device and bypass switch are installed and the system is in service from July 2013.
	100kW/90kWh battery supporting a grid-connected PV charging station for 20 cars.	Battery storage units are installed and in service since July 2013.
Pecan Street Project Inc. Energy Internet Demonstration (LITHIUM-ION BATTERY)	6kW/6kWh Sony Li-ion battery & 6kW/15kWh LineStar Energy Server Li-ion batteryBoth to be installed at Pike Powers Test Laboratory in Austin, TX.	Battery storage units are installed and are in service since May 2013. Other batteries are evaluated as well.
Kansas City Power & Light Green Impact Zone Smart Grid Demonstration (LITHIUM POLYMER BATTERY)	1MW/1MWh (13.2kV) Superior Lithium Polymer Battery Storage (SLPB) system, grid-connected.	Energy storage system installed and in service since June 2013.

Document number

Residential Solar Energy Storage Analysis

Prepared for NYSERDA

DNV KEMA
July 30, 2013

Scope

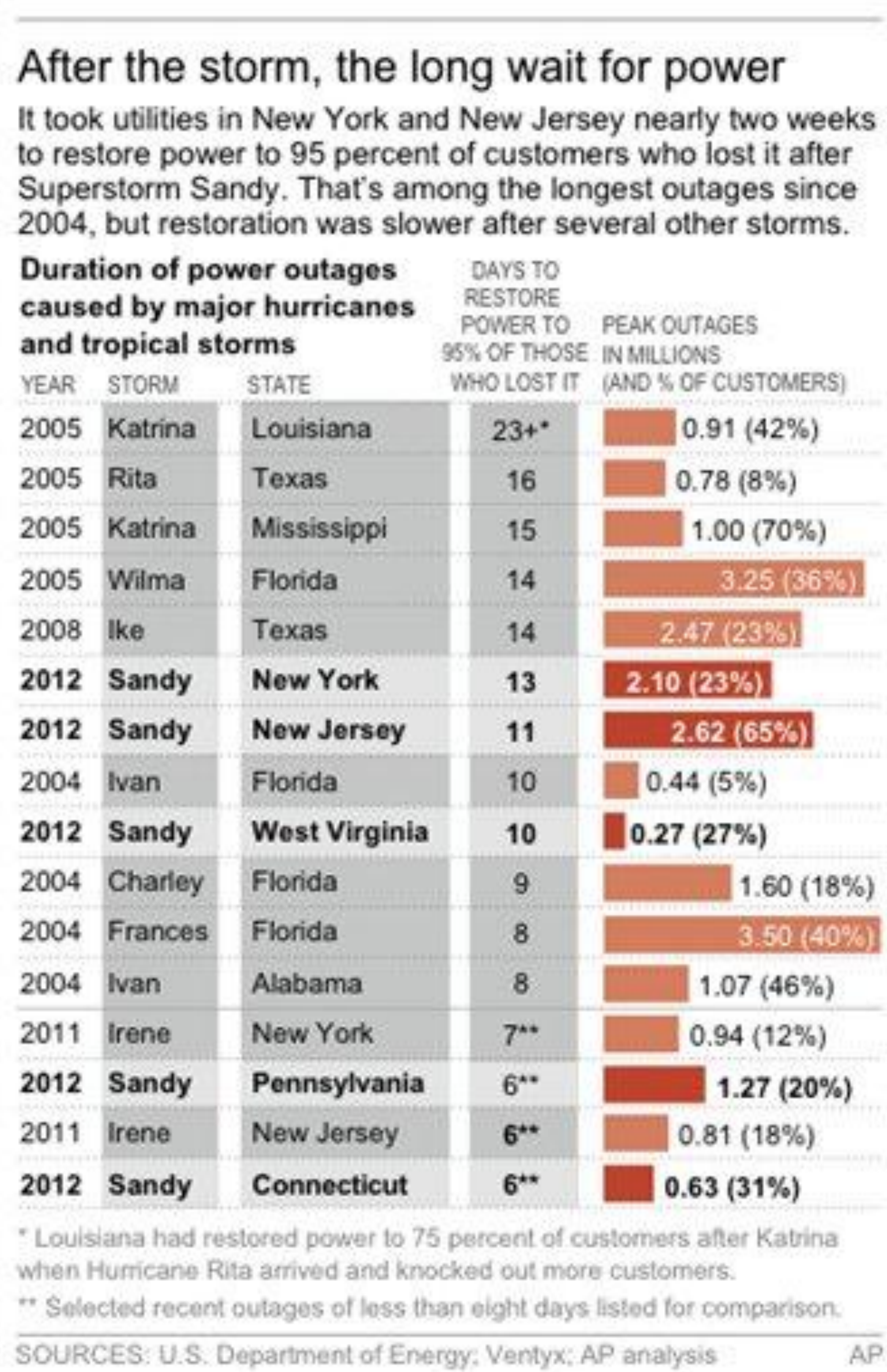
- In this study, the DNV KEMA team has examined the potential of storage applications to meet minimal electricity needs identified for residences, where grid failures prevented their distributed assets from operating during the outage
- Specifically, research has focused on the potential of solar–storage applications with the goal of:
  - Identifying lowest incremental cost to allow solar PV systems to island from the electric grid and provide a modest level of electricity for critical loads through these types of configurations
  - Identify niche applications close to commercialization for stationary energy storage that could be further supported by NYSERDA’s research, demonstration and deployment programs

<u>Disclaimer</u>: This analysis is an initial expedited attempt to quantify the minimum system sizing to provide minimal electric backup for a residential PV system and should be used as a reference document for those purposes. In addition, the examples of energy storage applications for the Commercial and Industrial sector presented at the conclusion of the document are not intended to be all encompassing.

Contents

Motivations

- Recent natural disasters have increased visibility of electric power systems and their interdependence
- After Hurricane Sandy, New York utilities restored power to 95 percent of customers 13 days after peak outage reporting
- Extended outages result in economic, security, and consumer confidence problems:
  - Frozen water pipes
  - Dark nights (increased fire danger)
  - Spoiled food
  - No electric heat
  - No elevators for the infirm or elderly
  - No means to charge mobile communication devices



After the storm, the long wait for power

It took utilities in New York and New Jersey nearly two weeks to restore power to 95 percent of customers who lost it after Superstorm Sandy. That's among the longest outages since 2004, but restoration was slower after several other storms.

Duration of power outages caused by major hurricanes and tropical storms

YEAR	STORM	STATE	DAYS TO RESTORE POWER TO 95% OF THOSE WHO LOST IT	PEAK OUTAGES IN MILLIONS (AND % OF CUSTOMERS)
2005	Katrina	Louisiana	23+*	0.91 (42%)
2005	Rita	Texas	16	0.78 (8%)
2005	Katrina	Mississippi	15	1.00 (70%)
2005	Wilma	Florida	14	3.25 (36%)
2008	Ike	Texas	14	2.47 (23%)
2012	**Sandy**	**New York**	**13**	**2.10 (23%)**
2012	**Sandy**	**New Jersey**	**11**	**2.62 (65%)**
2004	Ivan	Florida	10	0.44 (5%)
2012	**Sandy**	**West Virginia**	**10**	**0.27 (27%)**
2004	Charley	Florida	9	1.60 (18%)
2004	Frances	Florida	8	3.50 (40%)
2004	Ivan	Alabama	8	1.07 (46%)
2011	Irene	New York	7**	0.94 (12%)
2012	**Sandy**	**Pennsylvania**	**6****	**1.27 (20%)**
2011	Irene	New Jersey	6**	0.81 (18%)
2012	**Sandy**	**Connecticut**	**6****	**0.63 (31%)**

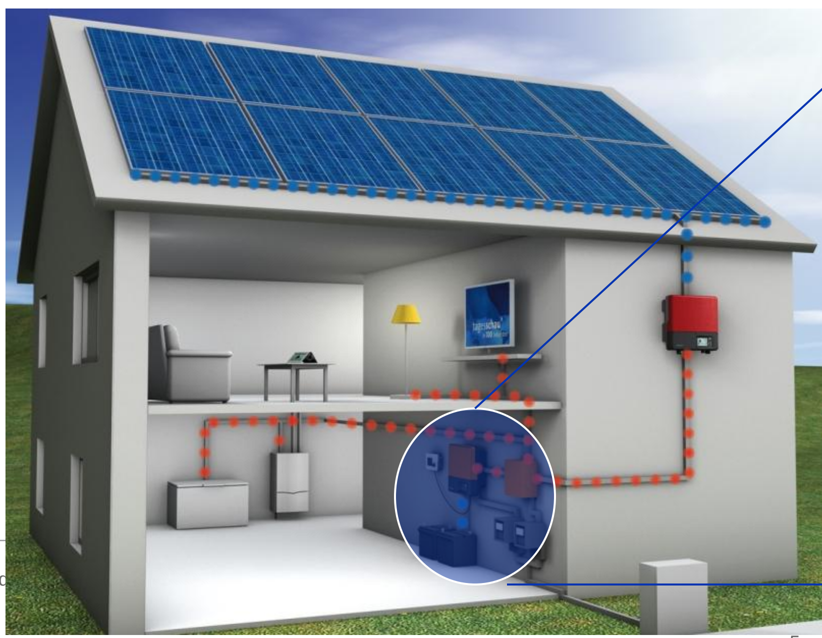
* Louisiana had restored power to 75 percent of customers after Katrina when Hurricane Rita arrived and knocked out more customers.

** Selected recent outages of less than eight days listed for comparison.

SOURCES: U.S. Department of Energy; Ventyx; AP analysis AP

Introduction

- These outages have exposed “gaps” in grid reliability
  - increased focus on utilization of distributed generation assets, notably photovoltaic generation to address these gaps
- An area of particular interest is allowing distributed generation assets to “island” from the grid during an outage
  - allows for continued power to critical systems such as health and safety, public safety, fuel distribution networks, telecommunication systems, and residences
- **This presentation will focus on “edge-of-grid” energy storage for residential backup and describes some near-term commercial and industrial applications**



Source: Sunny Backup by SMA

Source: Sunny Backup by SMA

Contents

Critical Loads

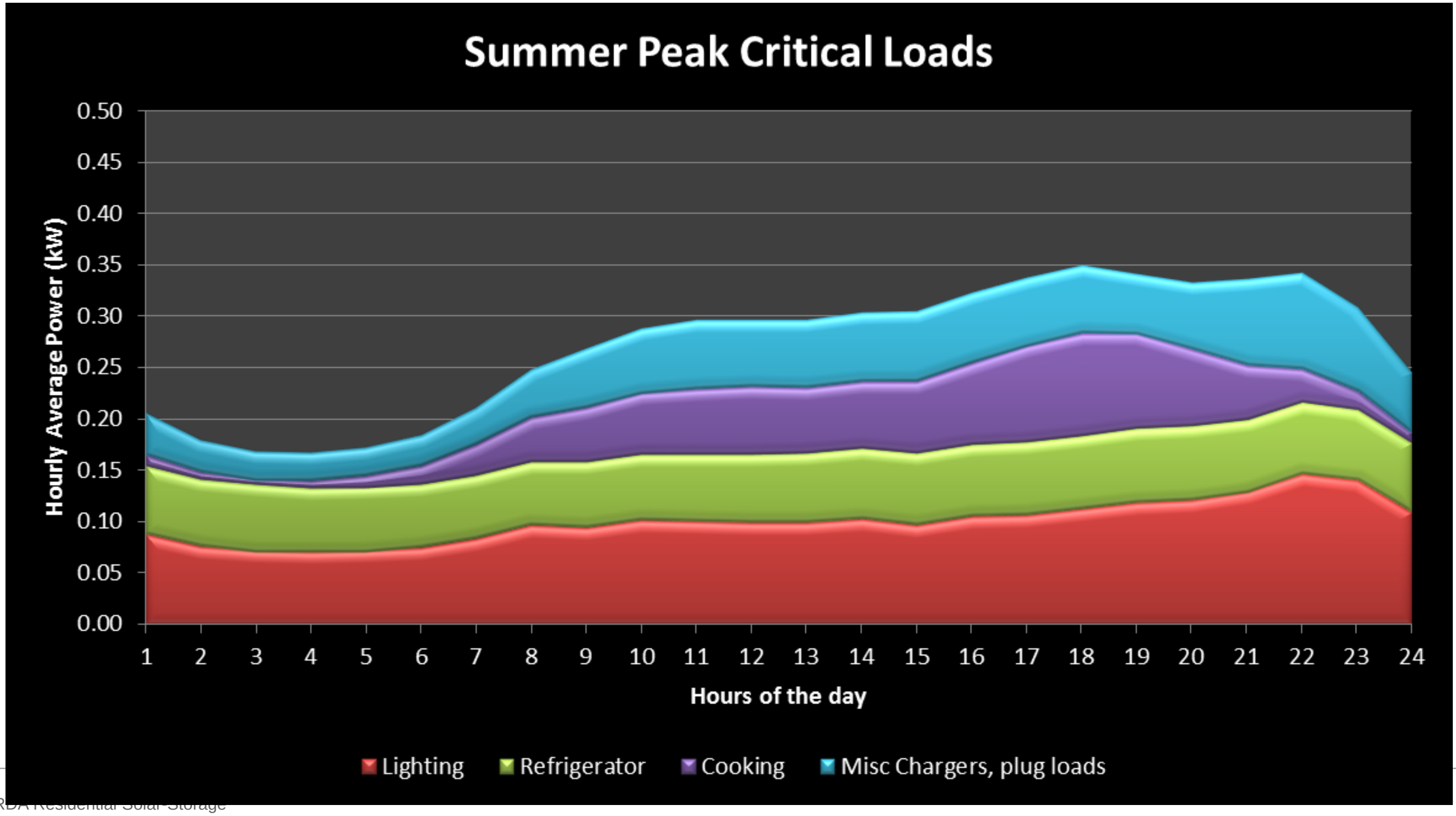
- It is not practical to design backup systems to support all electrical loads in a typical residence
- Customers and installers need to agree on which loads and circuits require backup during an outage
  - Power and energy requirements of critical load are the primary driving factors when sizing the storage device for back-up operation
- At a minimum, backed up loads may include communications equipment such as TVs or computers, select lighting, and a few outlets for charging mobile devices
- Additional desired backup may include fans and controllers for natural gas heating systems, water pumps, cooking, refrigerators and freezers

Establishing a Load Profile

- Capacity of the backup system is based on the power and energy requirements of the critical loads in relation to the duration of the grid failure
- Expected values of critical load can serve as a baseline to specify inverter and battery-capacity requirements
- The analysis here draws from Northeast residential load shapes for: heating, cooling, refrigeration, cooking, water heating, and misc. chargers and plug loads
- The data draws from the DNV KEMA load profile database for New York:
  - Electric Water Heater – DNV KEMA study for Northeast Energy Efficiency Partnership
  - Central A/C – DNV KEMA source
  - Electric Heating – DNV KEMA study for Northeast Energy Efficiency Partnerships
  - Non-electric Heating (pumps, fans) – DNV KEMA study for Northeast Energy Efficiency Partnerships
  - Lighting – DNV KEMA study for Northeast Energy Efficiency Partnerships
  - Refrigerator – Northwest Regional Technical Forum Data
  - Cooking – Northwest Regional Technical Forum Data
  - Misc Chargers, plug loads – DNV KEMA source
- *Tabulated data for each end use is shown at the end of the report*

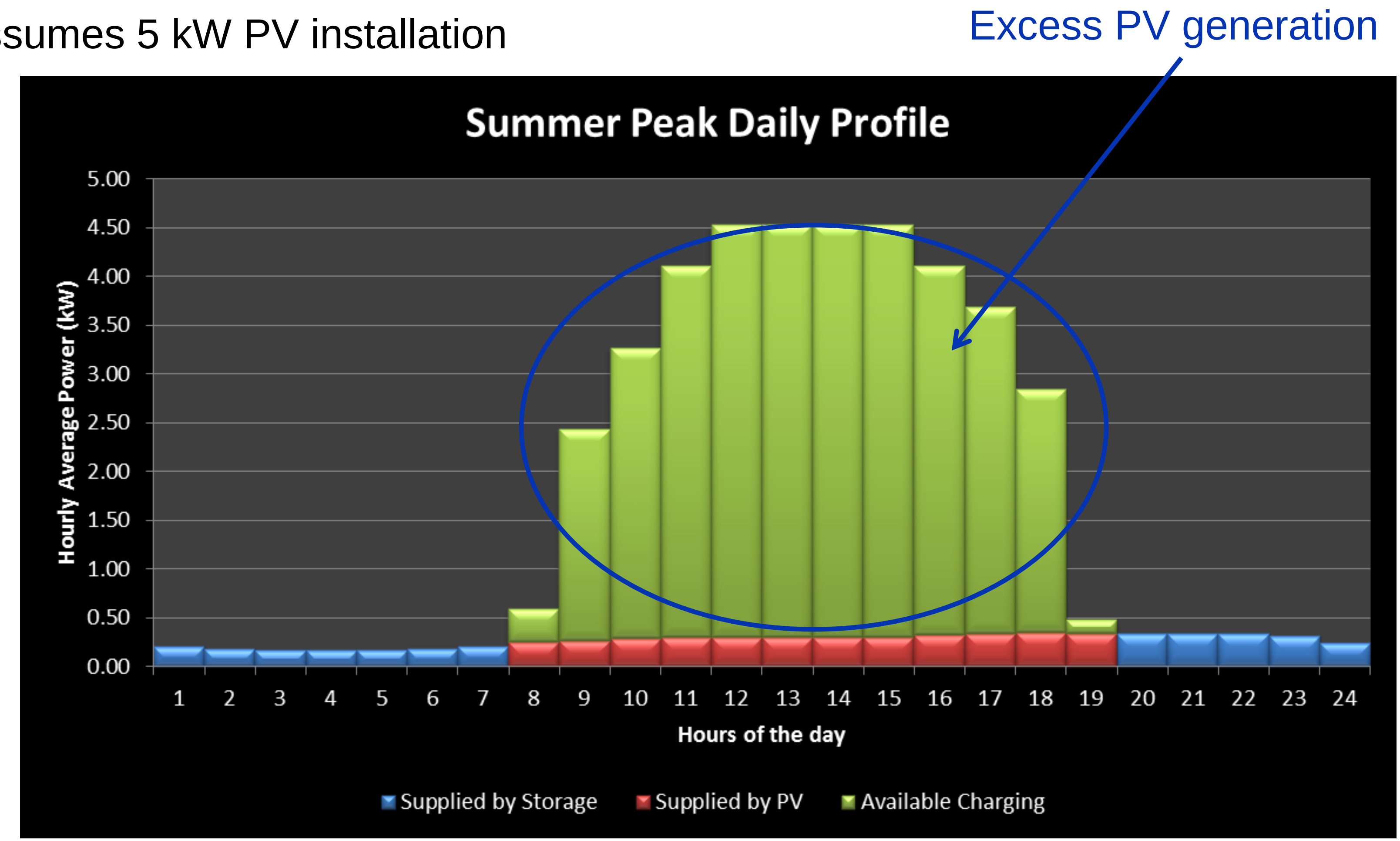
Summer Peak Residential Critical Load

- Graph shows hourly critical kW demand / kWh energy for a peak Summer day
- Central A/C and electric hot water heating were excluded from this minimal critical load analysis because their energy demands are so significant



Summer Excess Generation

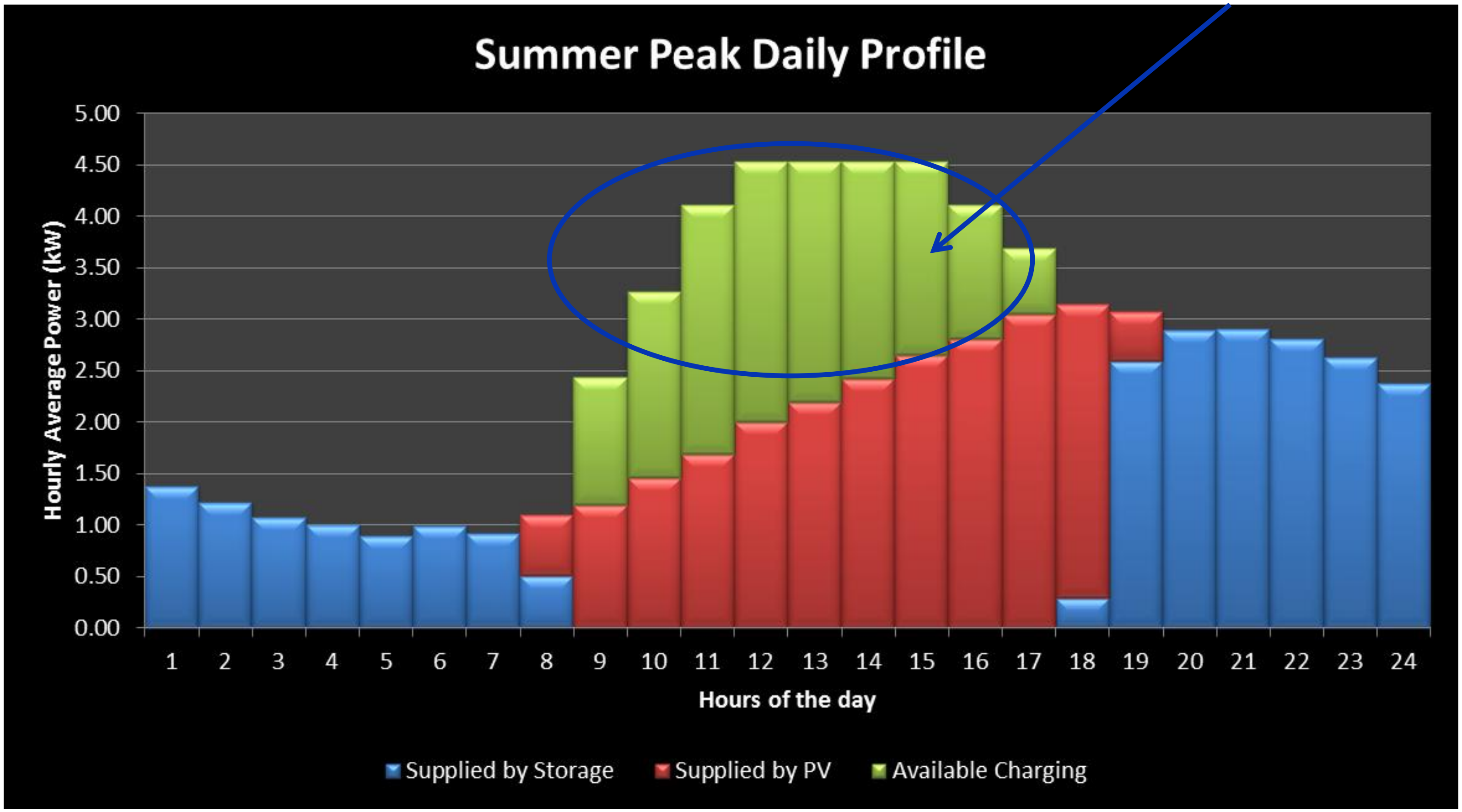
- Typical NY State Summer PV profile matched to critical load profile
- Assumes 5 kW PV installation



Summer Peak with Central A/C

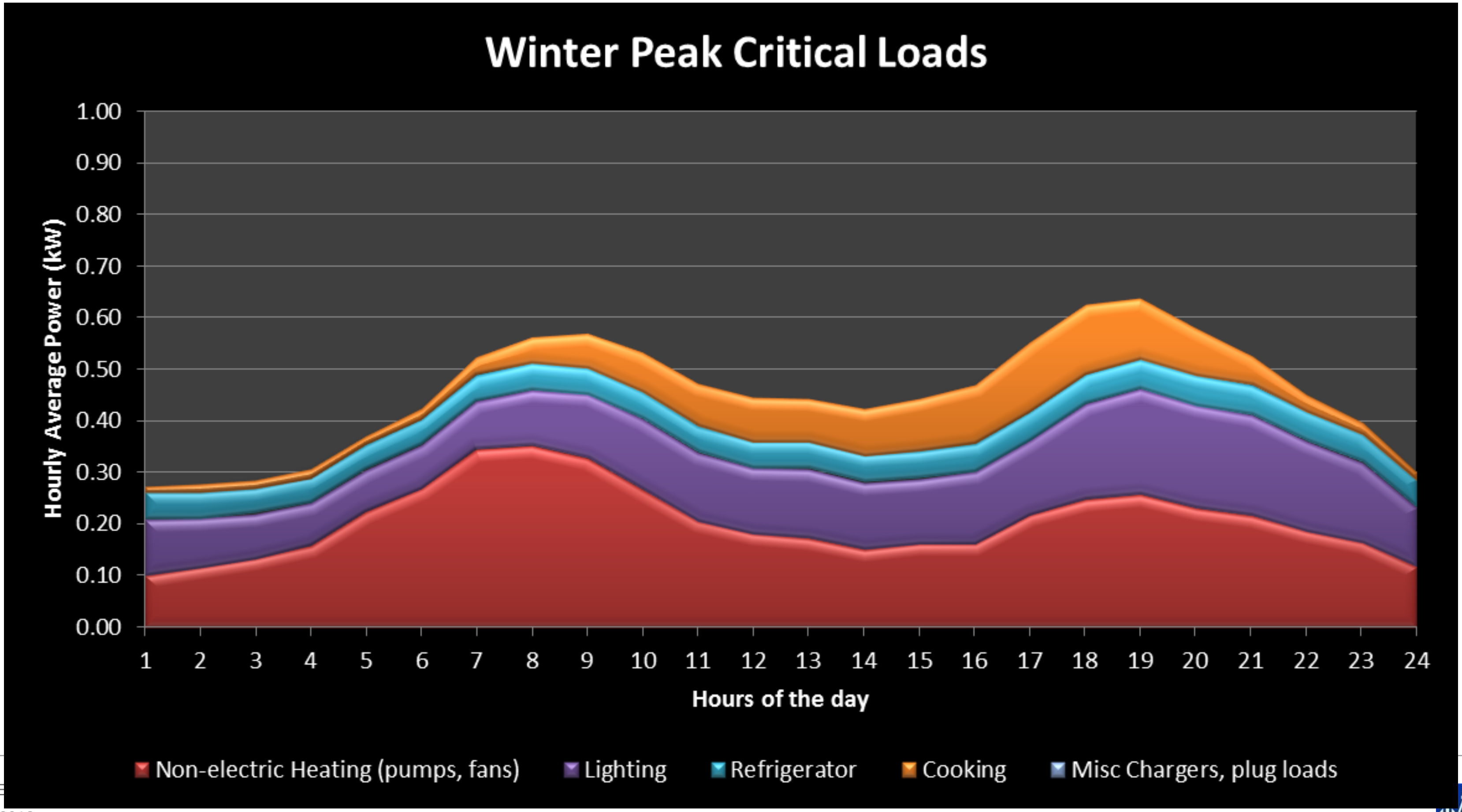
- Backup solar-storage system cannot support air-conditioning load in the event of an extended outage

Insufficient excess for charging



Winter Peak Residential Critical Load

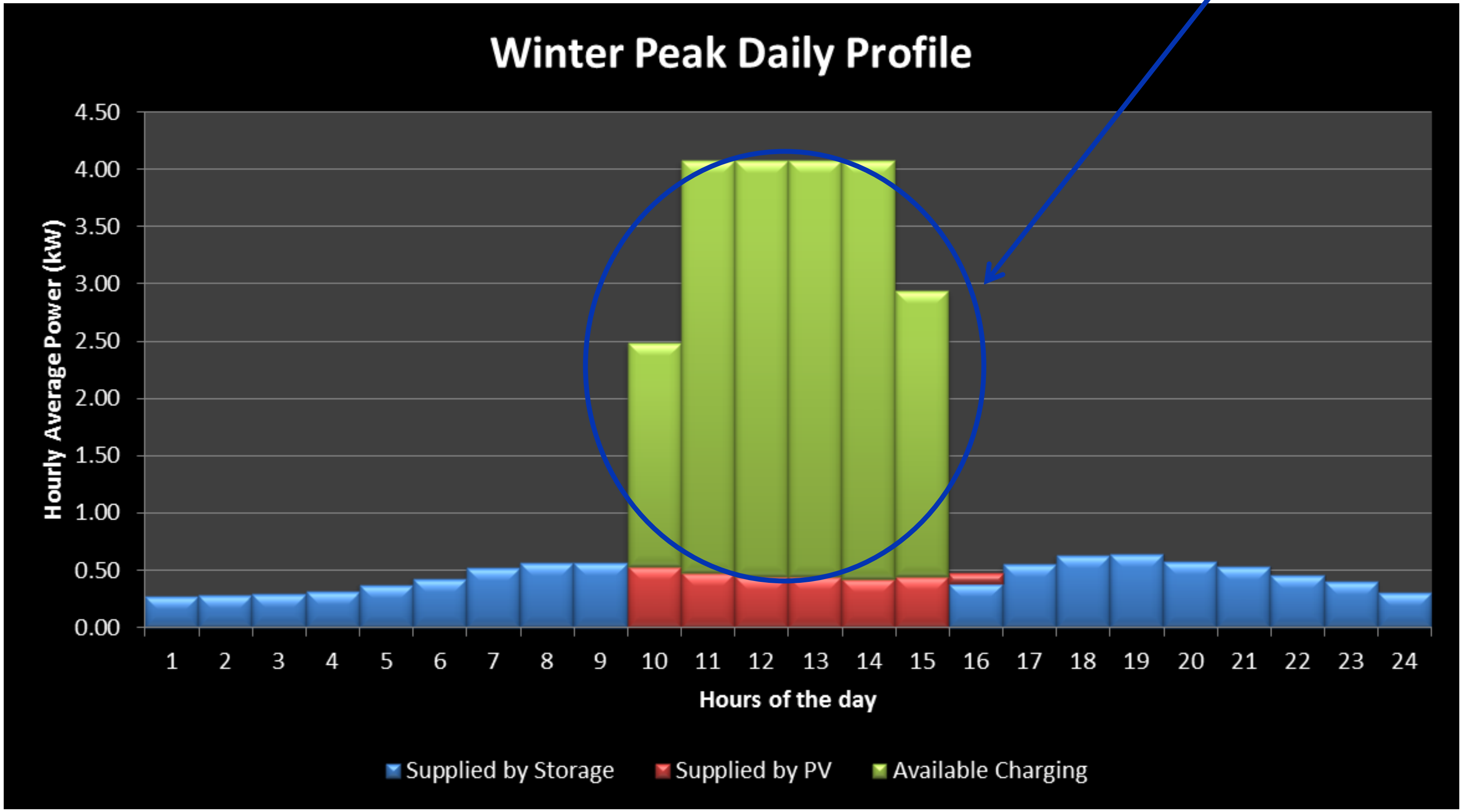
- Graph shows hourly critical kW demand / kWh energy for a peak Winter day
- Electric heating and electric hot water heating not included because of their significant energy requirements



Winter Excess Generation

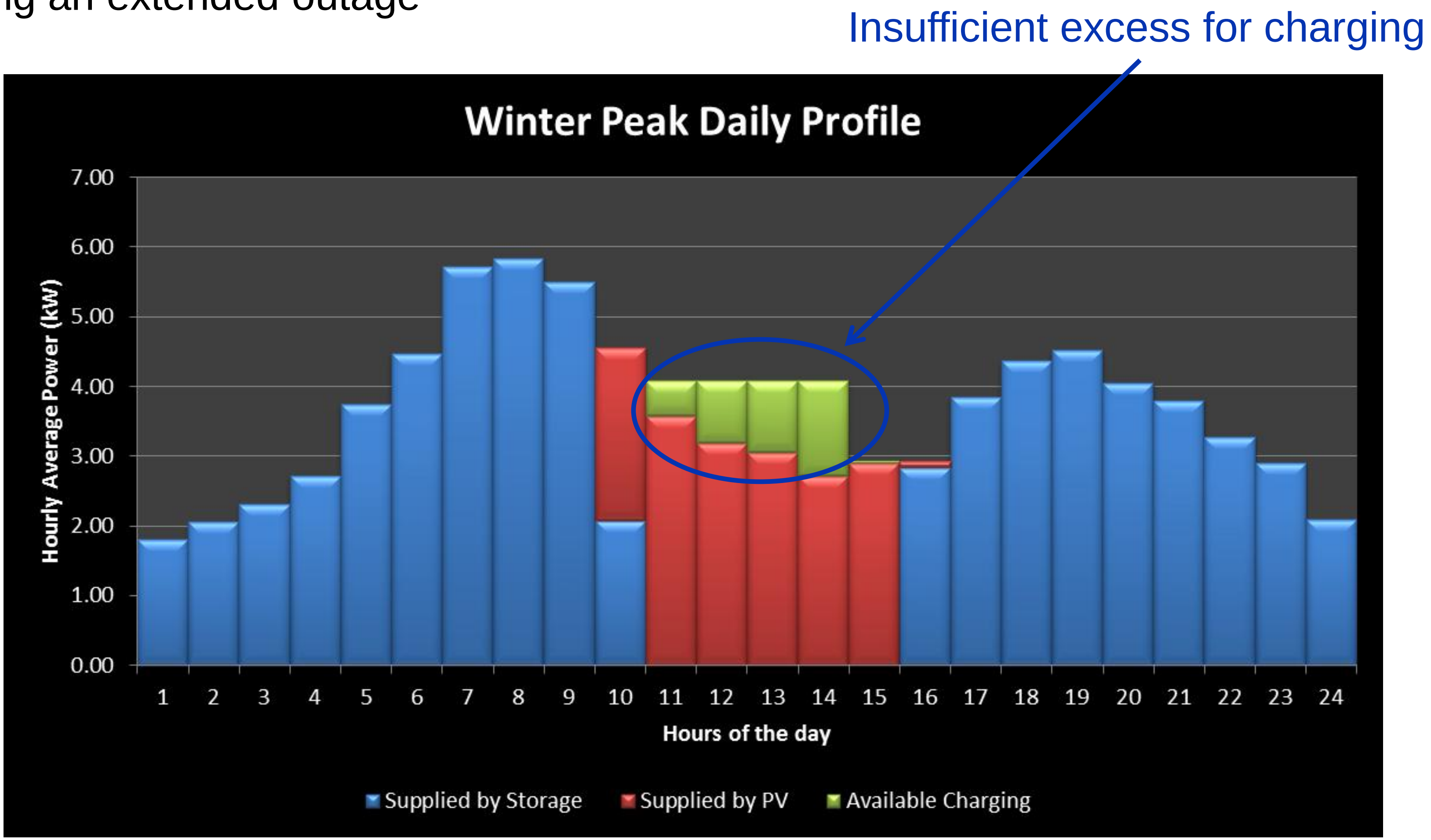
- Typical NY State Winter PV profile matched to critical load profile
- Assumes 5 kW PV installation

Reduced PV in winter



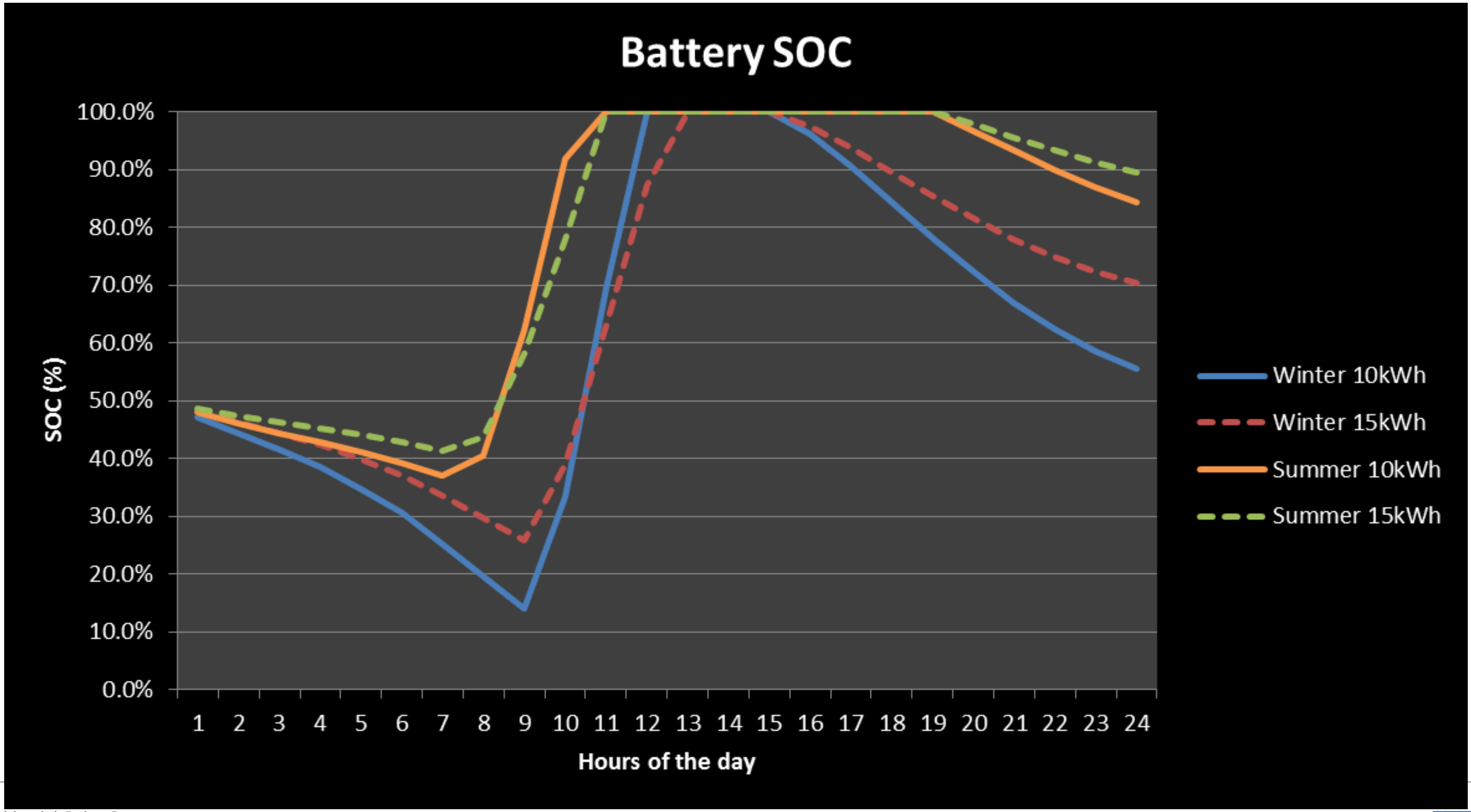
Winter Peak with Electric Heating

- Backup solar-storage system cannot support whole home electric heating load during an extended outage



State-of-charge of Storage for Critical Load Support

- During Summer, excess PV generation is sufficient to levelize storage state-of-charge for 10kWh storage capacity
- Winter load may require larger capacity and greater critical load management



Sizing Storage for Solar-Storage Backup

- For peak Summer load days, assuming 5 kW PV installation, potential exists for up to 25 kWh of excess generation
  - For a properly sized storage device, this excess is sufficient to maintain storage SOC for long term outages
- Peak Winter days can have significantly higher demand
  - Combined with reduced PV output, excess power to charge storage is limited
- Central A/C in the Summer and electric heating in the Winter are not considered as critical load as the power/energy consumption is too large
- If storage capacity is limited, homeowner may reduce the magnitude of critical load e.g. reduce lighting, hot-water heating, and plug loads to survive prolonged outages.
- The instantaneous peak power demand from critical loads can be multiple times of the hourly average consumption

Storage Requirements and Recommendations

Sizing Recommendations

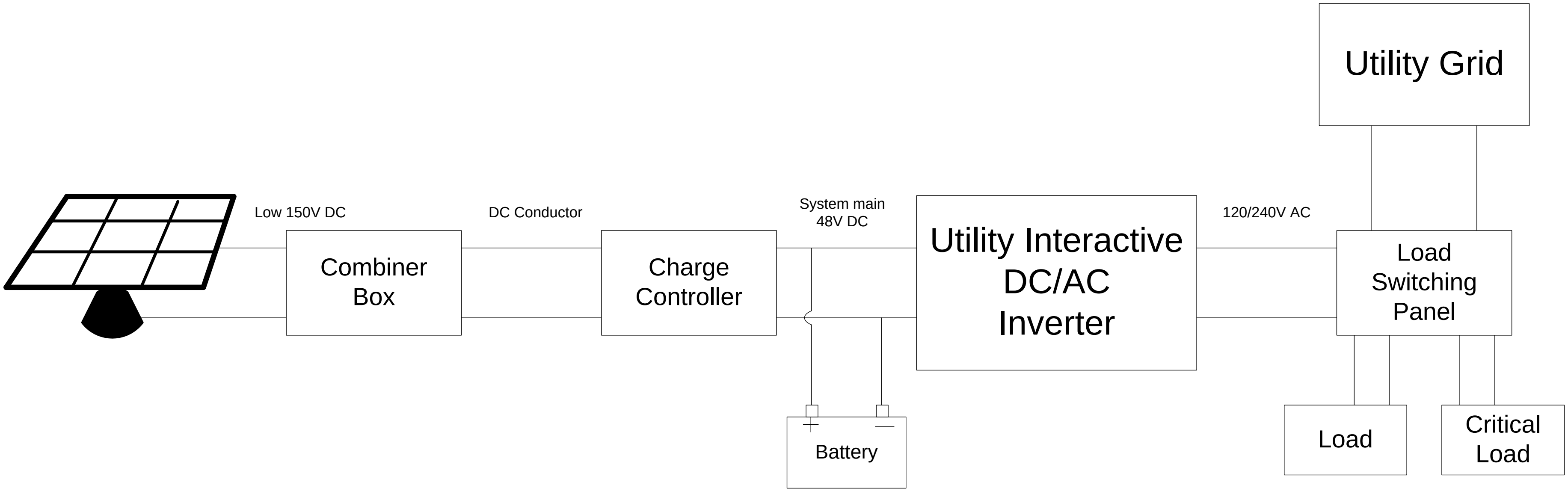
- DNV KEMA recommends sizing storage and required interconnection components at a minimum of 5kW for residential backup in New York
- DNV KEMA recommends a minimum of 10 kWh for residential back-up in New York,
  - energy rating of up to15 kWh may be necessary to survive prolonged outages during peak Winter days if electric hot water heating is installed, an alternative to larger storage capacity is a reduction in energy usage of critical loads during the outage

Balance of Plant and Control Recommendations

- To provide visibility and enable manual load management, DNV KEMA recommends solar-storage backup systems provide a means to monitor storage state-of-charge during backup operation
- In addition, advanced functionality such as automated and/or remote control of critical loads, through the system gateway or home EMS controller, may further improve survivability

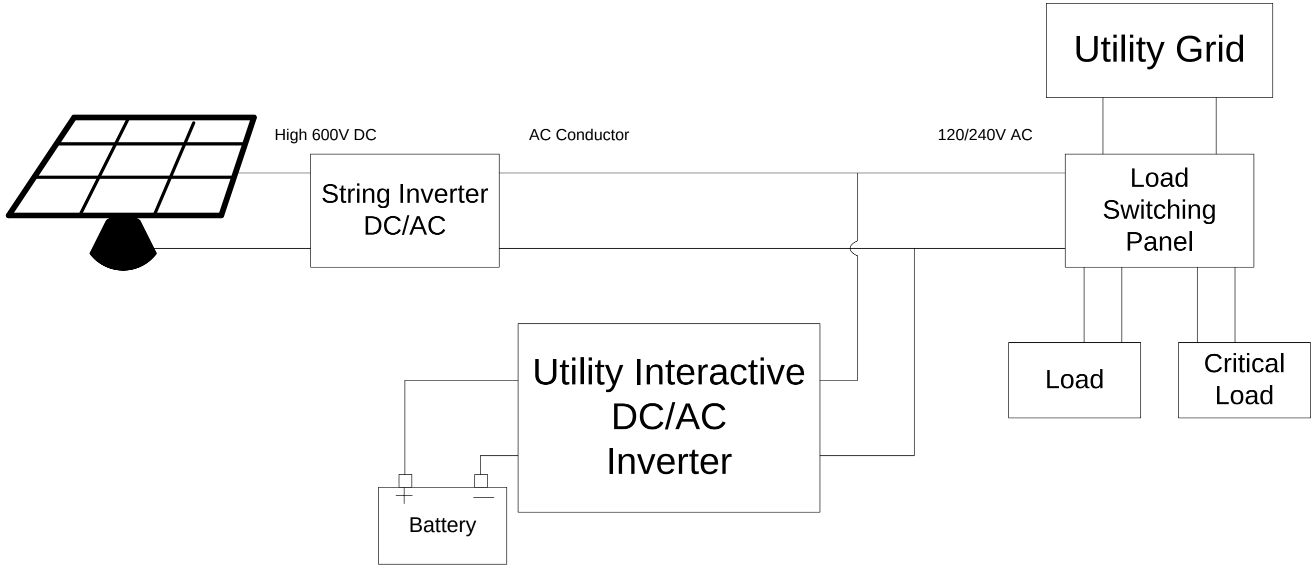
Contents

DC Coupling



- Traditionally, the majority of solar-storage systems have been DC coupled
- DC bus voltages typically operate at 150 - 600 V DC
  - higher voltages reduce losses and balance of plant costs
- Charge controller regulates DC current to prevent battery from overcharging

AC Coupling



- String inverters convert high DC voltage from PV array to 120/240V AC
- Similar overall cost to DC-coupled system
- Battery charge regulation techniques typically employ diversion loads and/or frequency phase-shift approaches to avoid overcharging storage
- AC coupling is seen by installers as the preferred approach for adding storage to existing PV systems

Inverters

- PV string inverters are *current-source* inverters
  - These convert power generated by a PV array from DC to AC, but rely upon an external AC source to operate as they cannot create an independent AC-voltage waveform
- Battery-based inverters do include *voltage-source* capable options.
  - These generate an AC voltage and frequency independent of an external AC power source
- Battery-based voltage-source inverters can provide a stable AC voltage and frequency reference that allows string inverters to operate when the grid is not present
  - In islanded mode, the AC power from string inverters is synchronized with the battery-based inverter output
- In a typical configuration, PV power can supply critical load first and the battery will be charged or discharged based on the mismatch between PV power and critical load
- The string inverter can be tripped off-line by a blackout relay, or by the frequency-phase shift function of the battery-based inverter

Diversion Load

- In a solar-storage charging systems, battery charging must be regulated to avoid over-charging
- The typical methods available for regulating the energy balance in AC-coupled systems are to either knock the string inverter off-line using a blackout relay or frequency-phase shift controller, or absorb excess generation using a diversion load
- If the PV array is much larger than necessary to charge the battery, excess power can be used to heat water, for example, by using a water heater as the diversion load
  - In operation, when battery voltage reaches the full charge setting in the charge control, it begins to divert power to the diversion load
  - The control uses pulse width modulation to turn the load on just enough to maintain battery voltage
- Using diversion loads to control excess generation provides more stable and reliable operation, as well as more sophisticated battery charging functionality

Some Additional Installation Considerations

- **Single manufacturer** – for installers, it can be advantageous to choose inverters, PV charge controllers and integration hardware from a single manufacturer for better compatibility
- **Battery enclosures** –enclosures must be designed to support the combined weight of the battery stack and provide adequate ventilation
- **Battery temperature sensing** – additional operational safety measurements should be employed to ensure optimal charging and prevent damage due to overcharging
- **AC bypass switch** – manually bypasses the inverters and connect the critical-loads panel to grid power during any required system maintenance
- **Dual AC inputs** – if the backup system design includes an engine generator, the design needs to specify inverters that have provisions for dual ac inputs, for example, grid and generator

SOURCE: https://solarprofessional.com/article/?file=SP5_5_pg74_Schwartz

Contents

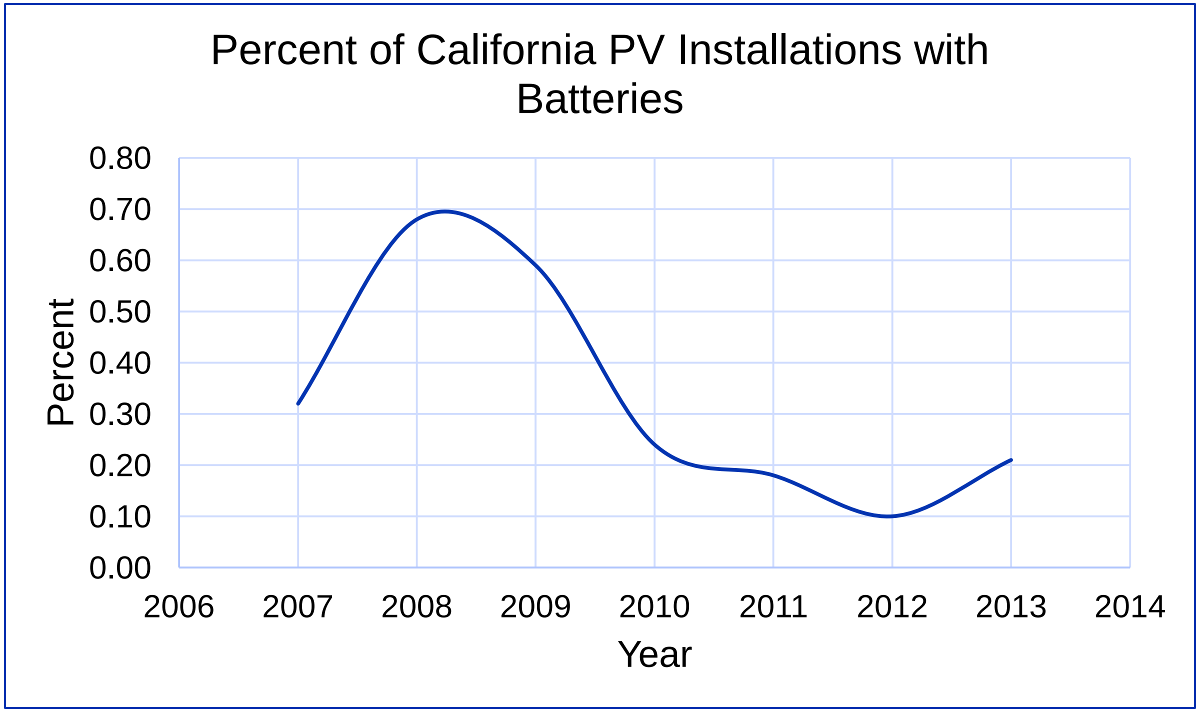
Case Study: California

- Comparison of the "installed cost" (before rebates or subsidies) of PV systems in California with and without energy storage over the last seven years is presented below
- It should be noted that these are "commercial" street costs excluding R&D and other overheads often included in many government-sponsored demo projects

	Res PV with batteries		Res PV (no battery) systems	
Year completed	# of systems	$/Watt	# of systems	$/Watt
2007	11	$ 11.61	3,420	$ 9.94
2008	52	$ 13.14	7,613	$ 9.90
2009	75	$ 12.30	12,628	$ 9.58
2010	38	$ 12.07	16,058	$ 8.49
2011	38	$ 10.26	21,411	$ 8.25
2012	29	$ 7.74	28,301	$ 7.06
2013	10	$ 7.88	4,729	$ 6.21

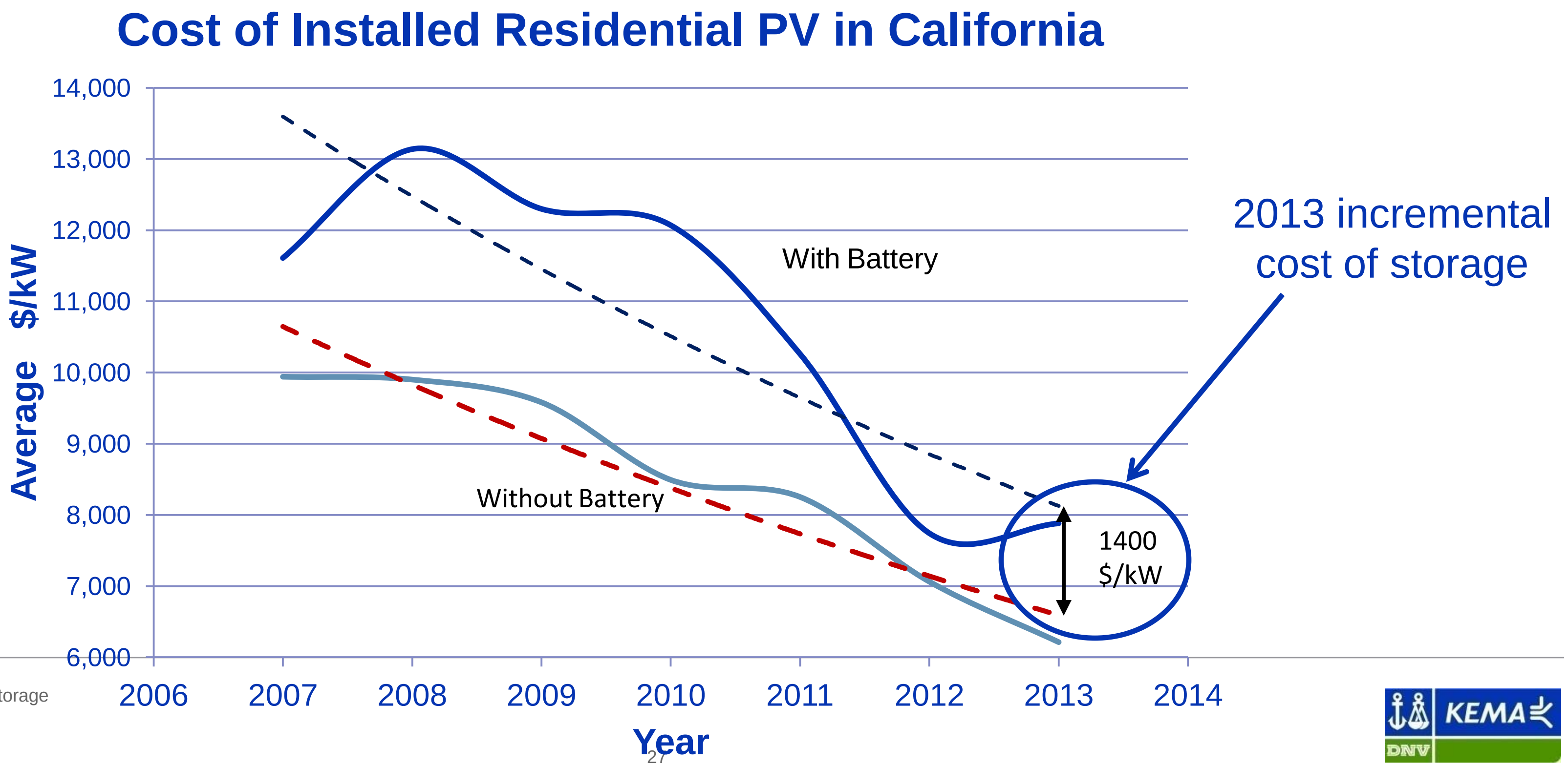
Case Study: California

- The PV installations with battery is about 0.4% of the total PV installations in California
- This ratio has been affected by the economic downturn that began in 2008



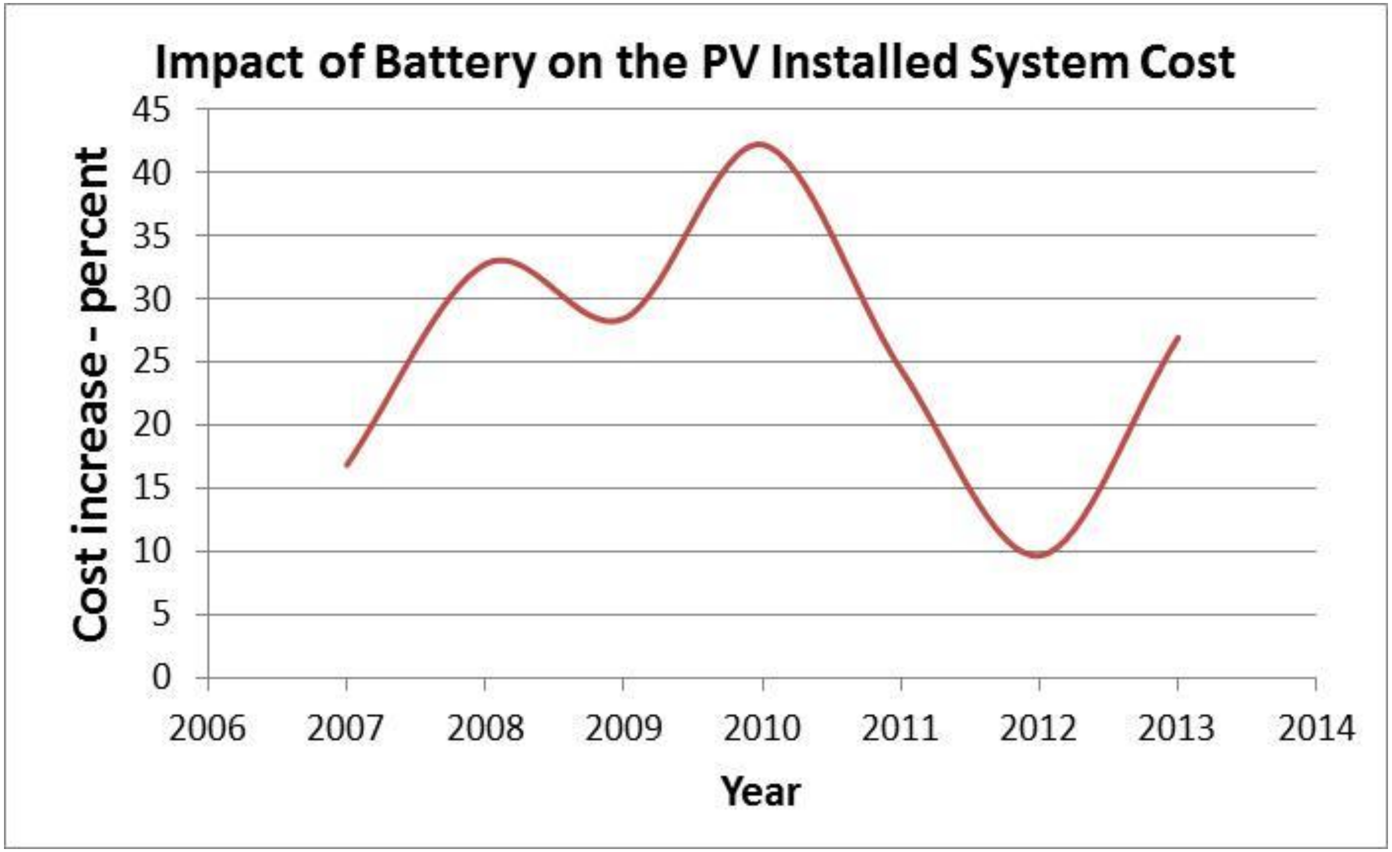
Case Study: California

- The cost of installed PV in California, with and without a battery, has been declining over the last several years at an average rate of 7% per year
- The incremental cost for having a battery added to a PV system has also been declining at an average rate of 11% per year
- Finding detailed data for each installation is difficult; our general belief is that these systems include supplying critical load



Case Study: California – Impact of Battery on installed cost

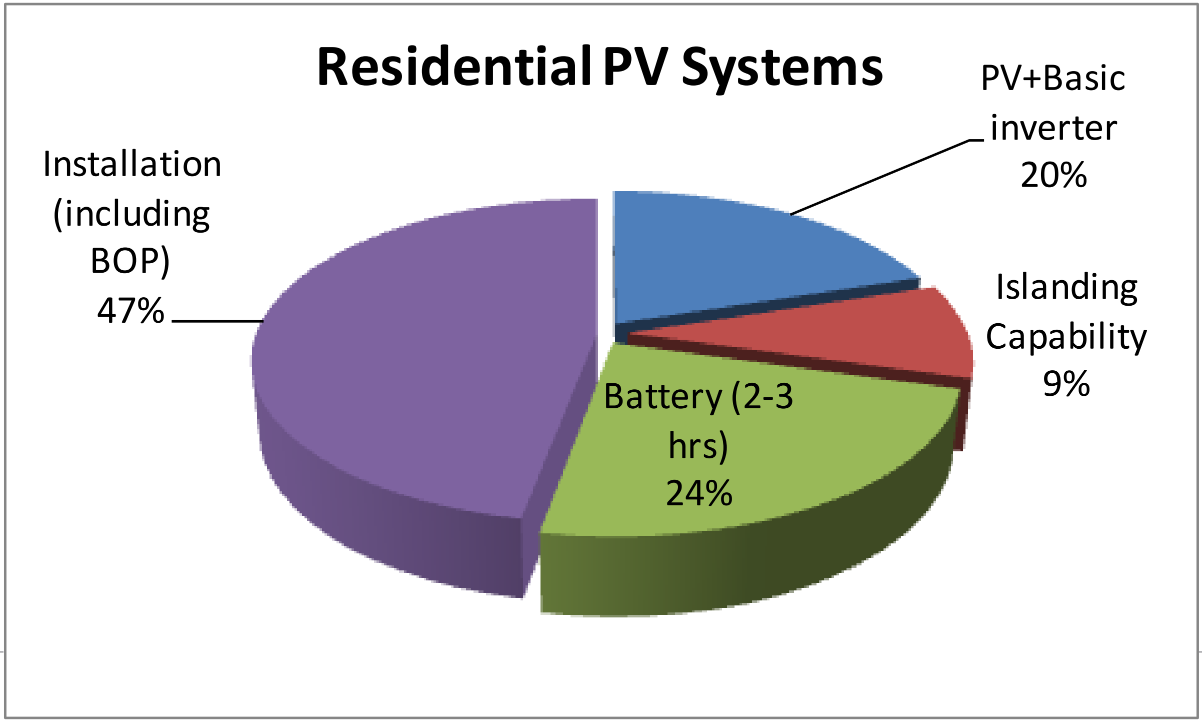
- Including a battery to PV increases the total installed cost by about 25%, depending on its capacity and capabilities



- Estimates put Li-ion replacement cost after 8 years to be 30-50% of complete system cost installed today. This is partly due to cost reduction and partly because certain BOP may be salvaged after 8 years.

Breakdown of Residential PV System Costs

- Depending on the type and size of the PV, inverter and the batteries used, the cost components vary but, on average, they may be generalized as follows:
  - Installation is about ½ the cost of an installed PV+ES system
  - Adding battery could double the PV hardware cost but its impact on the total installed cost is about 25 - 30%, depending on its capacity and capabilities.
  - Adding islanding capability to help PV system serve as a backup power could increase the installed cost by about 10%



Contents

Examples of Existing Solutions

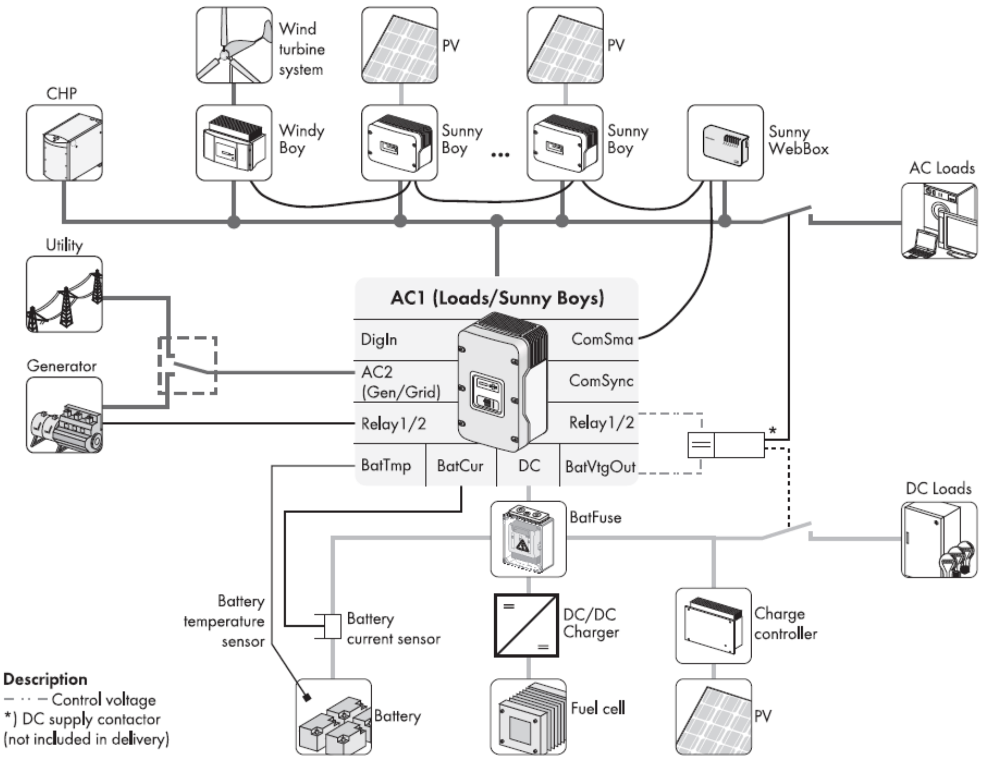
- Component Vendors
  - SMA America http://www.sma-america.com
  - Magnum Energy http://www.magnumenergy.com
  - OutBack Power Technologies http://www.outbackpower.com
  - Schneider Electric http://www.schneider-electric.com
  - RedFlow Battery http://www.redflow.com

- Integrators (packaged solutions)
  - Sunverge http://www.sunverge.com
  - SolarCity http://www.solarcity.com

- Demo projects
  - EcoCutie (Japan)

SMA America

- SMA has developed a high level of integration between its Sunny Island storage inverters and Sunny Boy string inverters in ac-coupled systems
- Functionality includes advanced frequency-shift battery charge regulation
  - capable of ramping up and down PV array charge current based on battery state of charge, a feature not available in AC-coupled systems using components from other manufacturers
- No diversion load is required since the charging current is regulated both on/off, and ramping up/down



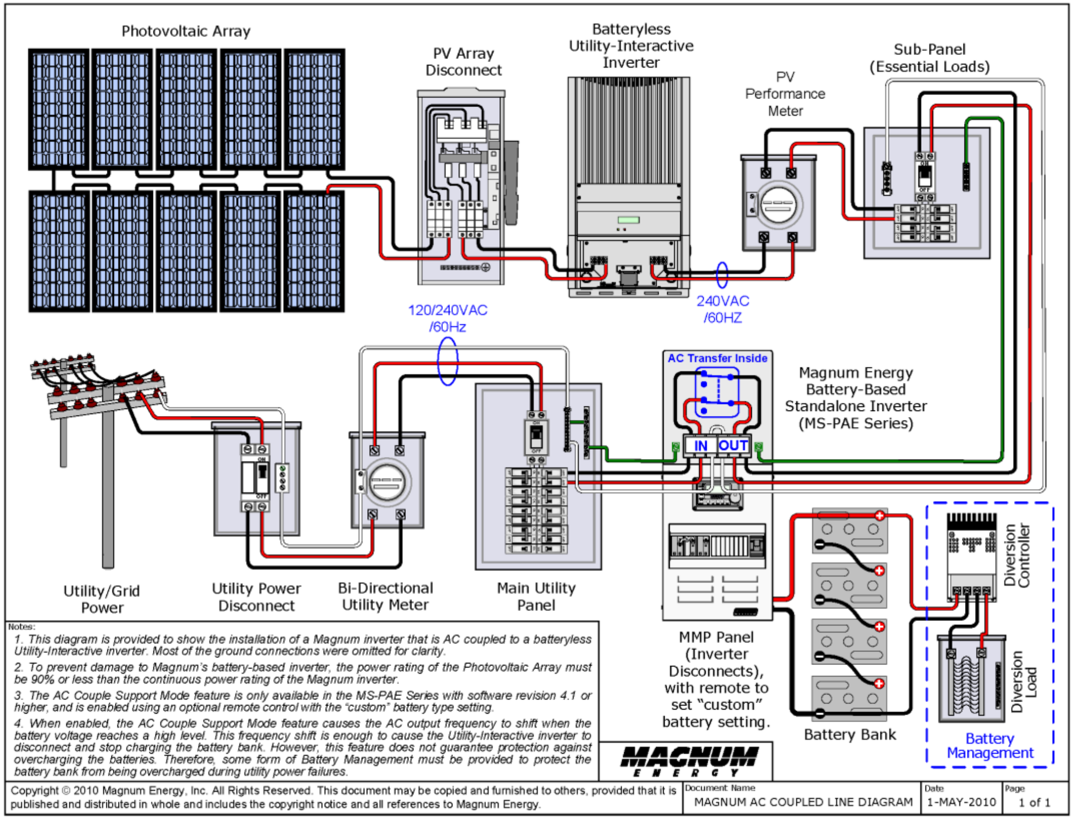
SOURCE: SMA America

SMA America

- SMA Sunny Island battery-based inverters and Sunny Boy grid-direct (string) inverters can be used in conjunction with one another and with backup generators to form a highly integrated stand-alone AC power grid
- As an add-on to the PV plant, the Sunny Island automatically switches to stand-alone power supply within approximately 20 milliseconds of a grid failure
- Both new and existing PV plants can be equipped with a Sunny Island System - with no effect on PV efficiency
- In addition to providing a backup system, the SMA Sunny Island enables storage of PV power produced during the day, for later use at night
- SMA sells batteries with their system: lead acid, flooded lead acid, and nickel cadmium battery, although other storage technologies may be integrated

Magnum Energy

- Magnum Energy designs and manufactures battery-based inverters for use in stand-alone applications and grid connected systems that require battery storage to provide uninterrupted power during utility-grid failures
- The Magnum Energy MS-PAE series inverter/charges can be used in AC-coupled applications



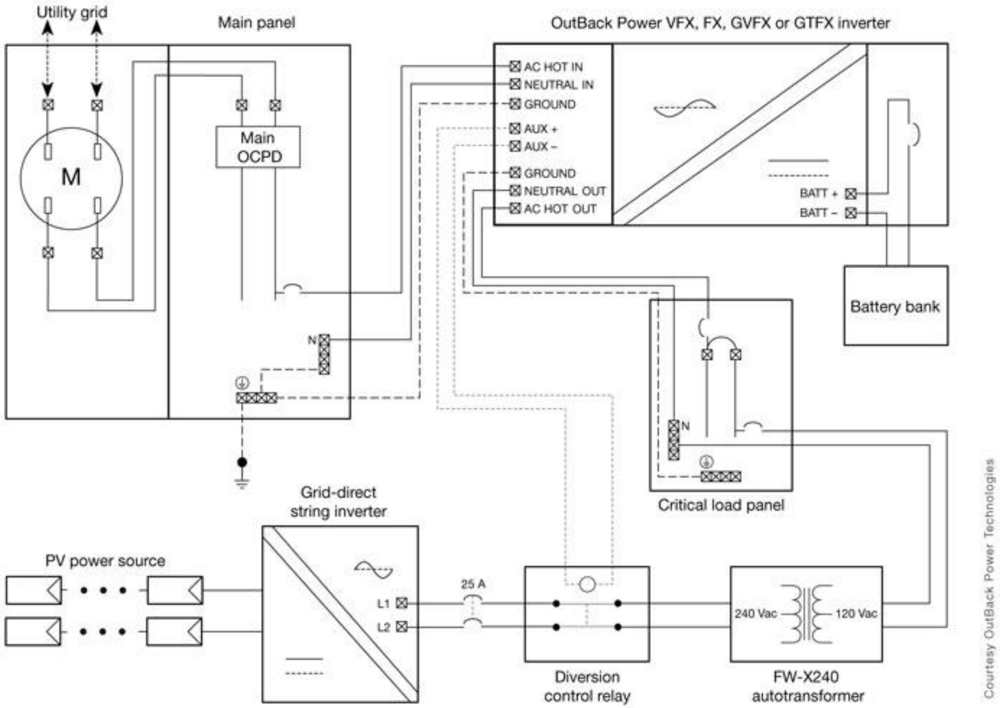
SOURCE: Magnum Energy

Magnum Energy

- Magnum Energy permits and supports AC-coupled system designs that synchronize the AC output of utility-interactive string inverters from various manufactures with its battery-based inverter/charges
- When the grid is operational, the Magnum battery-based inverter is in standby mode
  - Uses both utility grid and output of the string inverter to maintain charge on the battery bank
- When the grid goes down, the inverters disconnect from the grid and the battery bank begins supplying power to the critical loads; after 5-min, Grid-tie inverter will sync with Magnum inverter’s output and start supplying energy from the PV array
- Excess energy not consumed by the critical loads will return to the Magnum inverter and charge the battery bank
- Magnum recommends a diversion load, such as water heaters, as the primary battery charging protection approach, while using frequency-shifting as secondary approach

OutBack Power Technologies

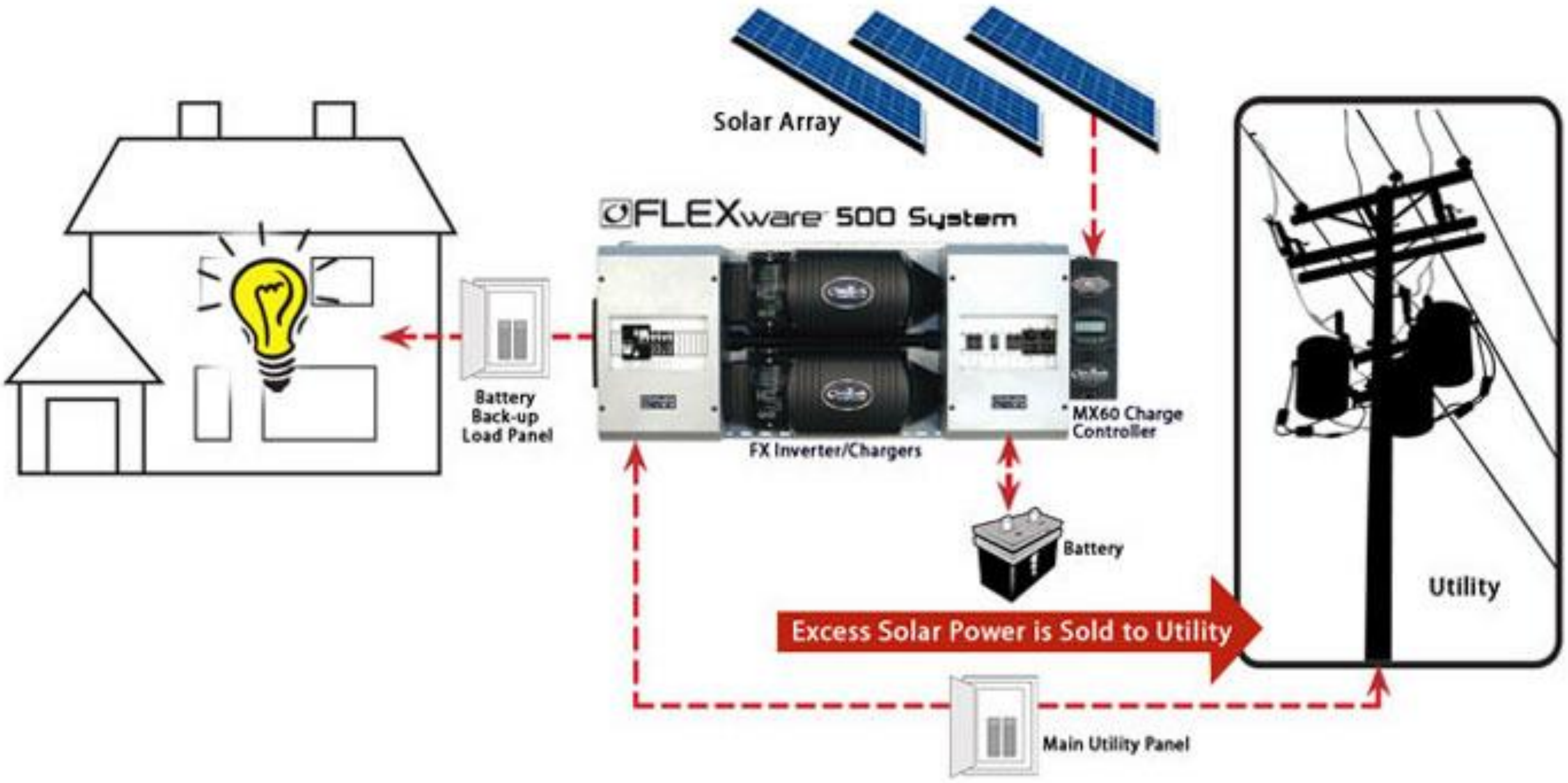
- OutBack Power Technologies designs and manufactures a full range of products, including stand-alone and utility-interactive battery-based inverters that can be utilized in both DC- and AC-coupled systems
- The OutBack FX (FX, VFX, GVFX or GTFX) single-phase inverter/charger series and Radian series support AC coupling



SOURCE: OutBack Power Technologeis

OutBack Power Technologies

- OutBack Power Technologies also offers power electronics and integration equipment that is primarily intended for use in DC-coupled systems



SOURCE: OutBack Power Technologeis

OutBack Power Technologies

- The FX series inverter/charges can be stacked in series and parallel in AC-coupled systems. When single FX inverter with a 120Vac output is coupled to a 240Vac string inverter, an OutBack autotransformer can be used.
- The Radian GS8048 is a utility-interactive inverter that can be stacked in parallel. It normally functions as battery-based inverter in AC-couple systems, but has capability of feeding excess power to the utility grid.
- Both OutBack Radian and FX inverters do not utilize frequency-shifting for battery management
  - Radian supports diversion loads and blackout relays, and the FX only supports blackout relays
- OutBack Power considers the battery-based inverter/charger must have enough capabilities to regulate voltage/frequency for PV string inverters and other backup generators in the case of utility grid is not present

Schneider Electric

- Schneider Electric designs and manufactures both utility-interactive inverters and battery-based inverter/chargers for the North American solar market
- The newest generation of Conext TX residential grid-direct inverters integrate with the Conext XW battery-based inverter/charger to create an AC-coupled system

AC-coupled

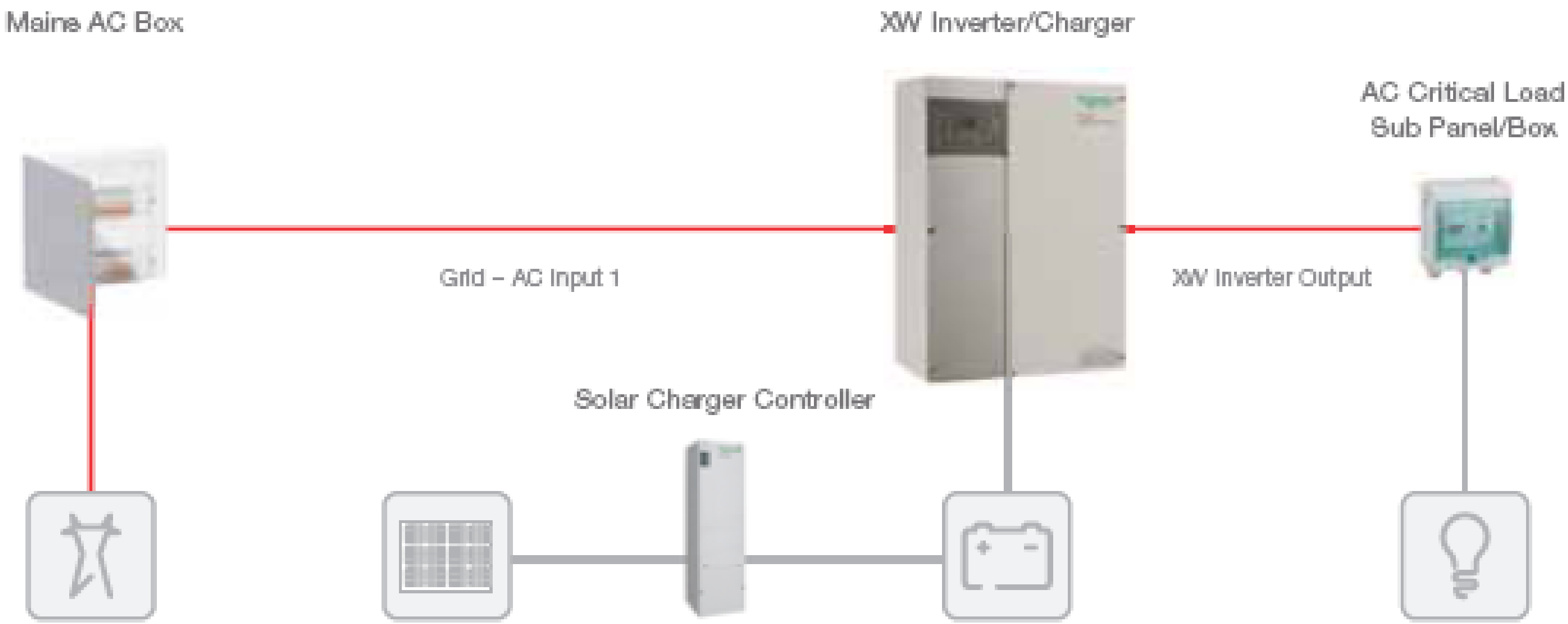
SOURCE: Schneider Electric

Schneider Electric

- Grid-present operation
  - When the AC source is qualified and is within the pre-set ranges, the XW inverter is connected to the source and behaves like a load charging battery
  - The TX grid-direct inverters synchronize with the utility-power reference and process power from the PV array
- Islanded operation
  - If the external AC source voltage or frequency deviates outside acceptable ranges, XW inverter is disconnected from the AC source by opening the input relays, and provides power to the critical loads
  - The TX grid-direct inverters detect temporary loss synchronization during transfer, and go off-line until detecting a stable AC output from XW for a minimum of 5 minutes
  - During utility failures, the XW serves as voltage source, and the TX inverters synchronize with the AC reference provided by XW inverter
- System regulation
  - The XW inverter uses frequency-shifting and on/off cycling to prevent overcharging

Schneider Electric

- Alternatives to AC coupling
  - If array-to-battery distance is the primary design driver for an AC-coupled system, user can weigh the potential cost and operational benefits of utilizing a DC-coupled system architecture with a higher voltage DC-charge controller
  - Schneider Electric manufactures charge controllers rated at 150Vdc and 600Vdc



DC-coupled

SOURCE: Schneider Electric

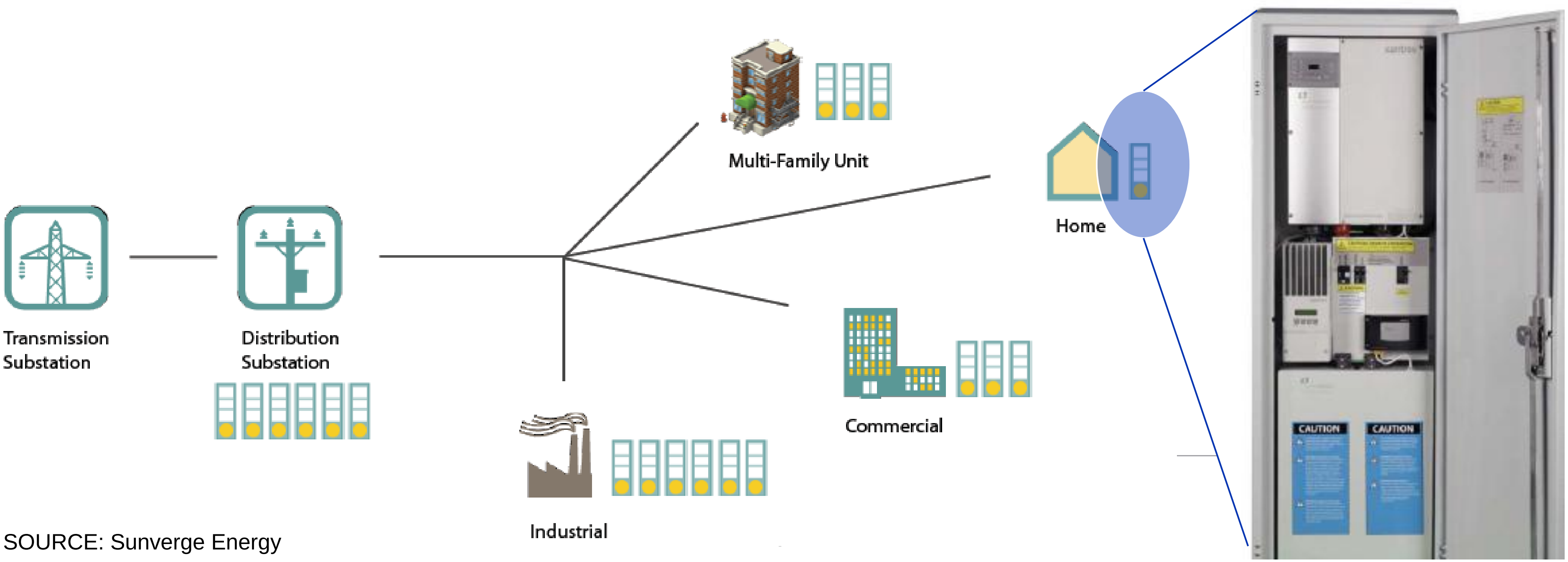
RedFlow Storage

- RedFlow offers a zinc-bromide module (ZBM) flow battery
- 61 energy storage systems were installed on Ausgrid network in 2011 and 2012 as part of a Smart Grid demonstration project
- R510 model rated at 5kW, 10kWh: comprised of one ZBM, SMA inverter, 3G modem for communications, battery management system (BMS), and remote terminal unit (RTU) housed in a metal enclosure

SOURCE: Redflow

Sunverge Energy

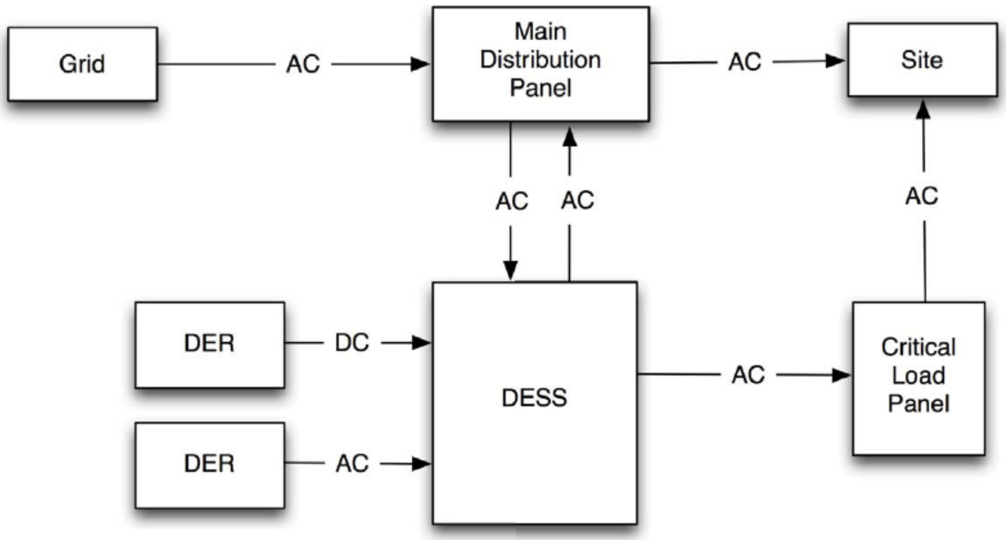
- Sunverge solar integration system consists of a 6 kW Schneider hybrid inverter and 10.77 kWh Li-Ion storage (capacity available up to 15.1 kWh)
  - unit is self-contained and sits behind the meter, NEMA 3 enclosure for indoor or outdoor installation
- Gateway used by the consumer to select loads that will operate in back-up mode
- Current system operates at 150 VDC, currently working on a model which can operate at both 150 V and 600 V



SOURCE: Sunverge Energy

Sunverge Energy

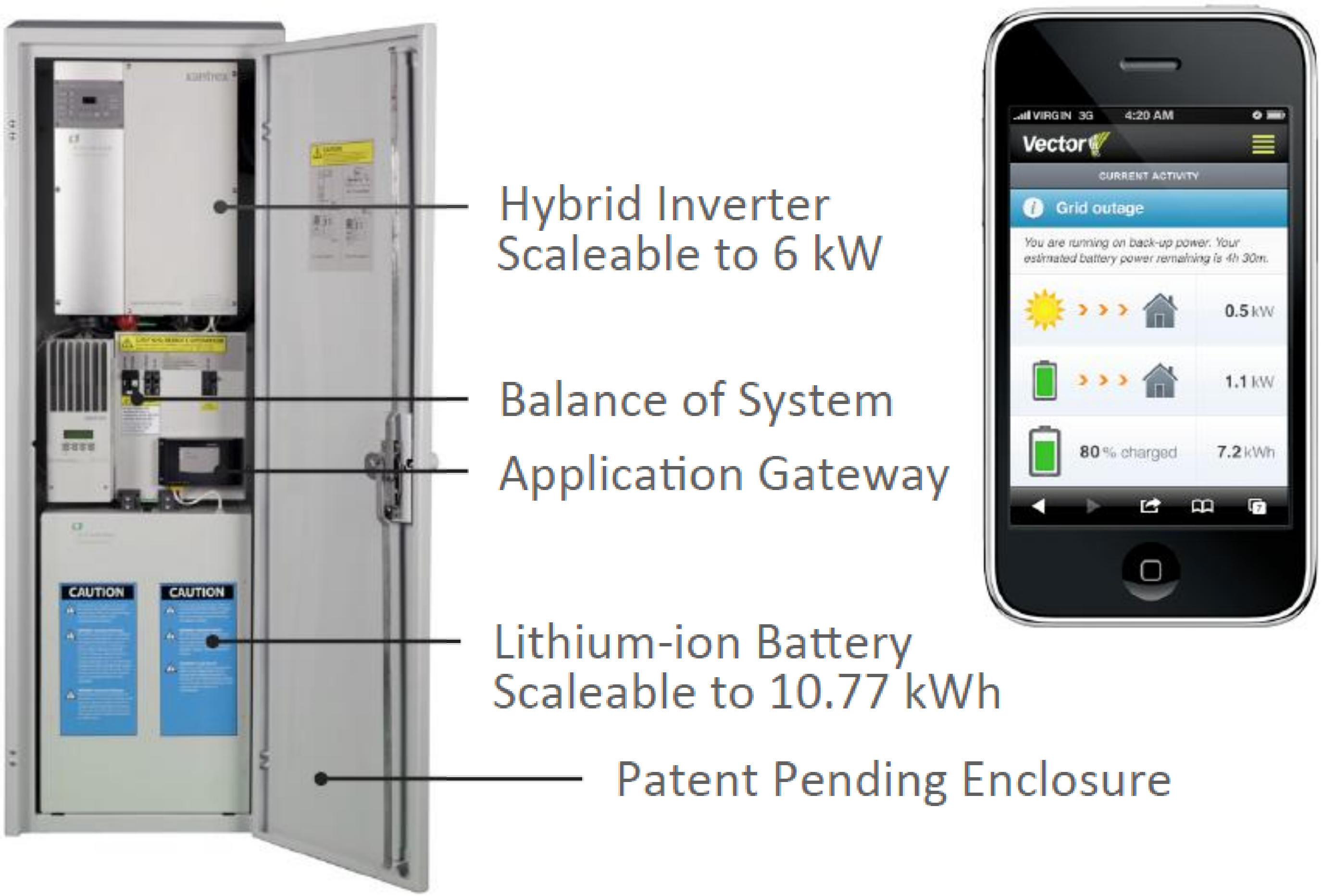
- Sunverge solar integration system
  - Intelligent communication platform through which utilities can send instructional demand response and load management messages to their customers
- Inclusion of storage allows for participation in utility demand response programs, even when not convenient for consumers
- UL 1741and IEEE 1547-- compliant anti-islanding
- Sunverge Home Area Network allows for in–home or remote wireless interfaces, homeowners can turn lights on and off loads and program run time of appliances
- Power Architecture:



SOURCE: Sunverge Energy

Sunverge Energy

- Currently 38 installations on-line, with 184 planned by 6/13 and 400 by end of 2013



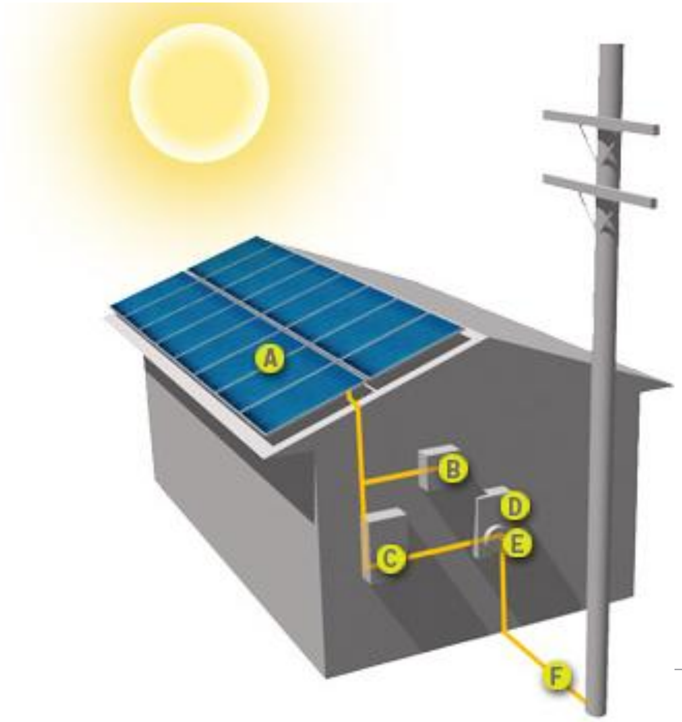
- Software application for remote monitoring of resources and storage state-of-charge

SOURCE: Sunverge Energy

SolarCity

- Developed a wall mounted residential storage product, selling residential product today
  - 5 kW, 10 kWh, primarily Li-Ion with some advanced lead acid installations
- Interconnection built around SMA Sunny Island platform
- Works with customers to select critical loads to be powered during an outage

  - A – Solar Panels
  - B – Battery Storage
  - C – Inverter
  - D – Electrical Panel
  - E – Utility Meter
  - F – Utility Grid



SOURCE: Solar City

SolarCity

- Close partnership with Tesla Motors
- Primarily selling in CA because of SGIP funding for energy storage
  - SGIP rebate has made system installation cost-effective
  - System operates in parallel with the grid but also provides battery back-up
  - Where allowed by tariffs, the system can perform market participation
- Over 70 SGIP applications for storage installations in 2012
- Solar lease program has signed on 21,000 customers in 2012
- Have not focused on Eastern US markets on residential, because of CA incentives

Eco-cutie System in Japan

- NEDO demonstration project from 2002-2008
- About 550 PV systems were installed on the roofs of houses in a single subdivision and connected to the utility in the demonstration research area in Ohta, Japan. The total nominal output power is more than 2 MW.
- The capacity of the PV systems was chosen to be 3 to 5 kW because this is the standard capacity of residential PV systems in Japan
- A lead-acid storage battery system was installed in all PV systems.
  - The lead-acid battery had a capacity of 9 kWh or 4,900 Ah, the upper bound regulated by the Fire Service Law in Japan.
- Both AC and DC configurations were tested for solar-storage systems

Eco-cutie System in Japan

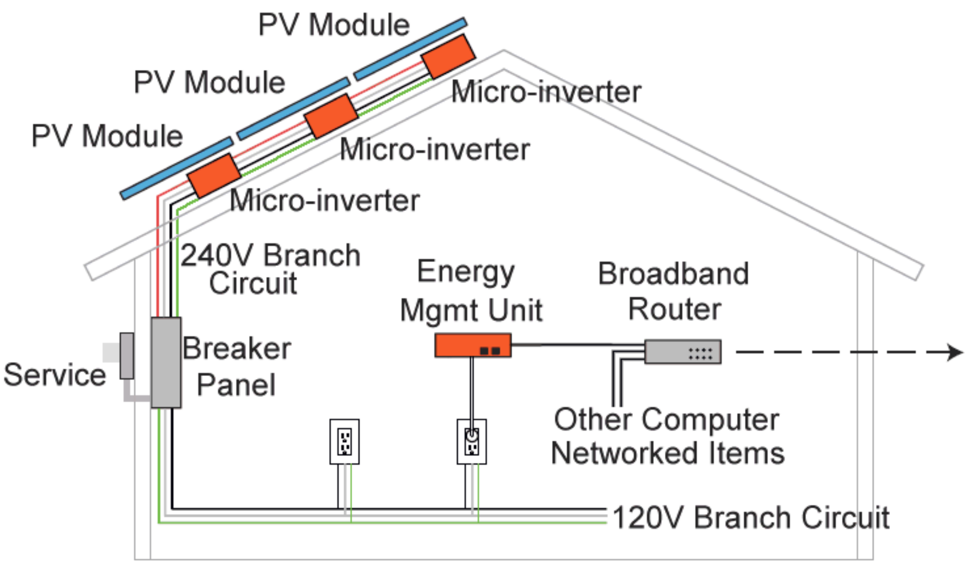
Contents

Micro-Inverters

- Established technology
  - Most common where array sizes are small, less impact from increased $/Watt for system
- Micro-inverters are attached to each solar module, versus at ground level for a typical centralized string inverter
  - up to 300 W per inverter
  - each inverter can operate in MPPT mode for its panel
- Main advantage is that shading, debris and/or snow lines on any one solar panel do not disproportionately reduce the output of the entire array
  - only the output of the affected modules are impacted
  - all the other modules will operate at their optimal efficiency
- Another key advantage is easier implementation of gradual deployment
- Disadvantages include high equipment and installation costs, higher likelihood of inverter failure
- Micro-inverters have not experienced the same sharp price decrease seen for panels and centralized inverters

EnPhase Micro-Inverters

- First commercially successful micro-inverter
- Over one million units shipped
- Software gateway allows for monitoring resolution to individual panel



Typical Enphase Energy System

SOURCE: Enphase Energy

Enecsys Micro-Inverters

- U.K. Micro-inverter manufacturer
- First VDE AR-N 4105 compliant micro-inverter:
  - New German requirements on power quality, reactive power control and power phase balancing capabilities

SOURCE: Enecsys

Micro-Inverters – Integration with Battery Inverters and Cost

- Power-One's AURORA Micro 250 W and 300 W products (released 2012)
  - Not yet tested with battery-based inverters in ac-coupled applications
- SMA America has released a Sunny Boy 240 (240 W) micro-inverter
  - Designed to be compatible with SMA's Sunny Island system with special considerations
- Lux Research estimates that the cost of micro-inverters average between $0.50/watt and $1.00/watt, compared to string inverters which range between $0.25/watt and $0.50/watt
- The cost of power optimizers ranges widely, anywhere from $0.10/watt to $1.00/watt

SOURCE: http://www.solarserver.com/solar-magazine/solar-report/solar-report/microinverters-and-power-optimizers-perspectives-of-distributed-pv-system-architecture-in-the-residential-market.html

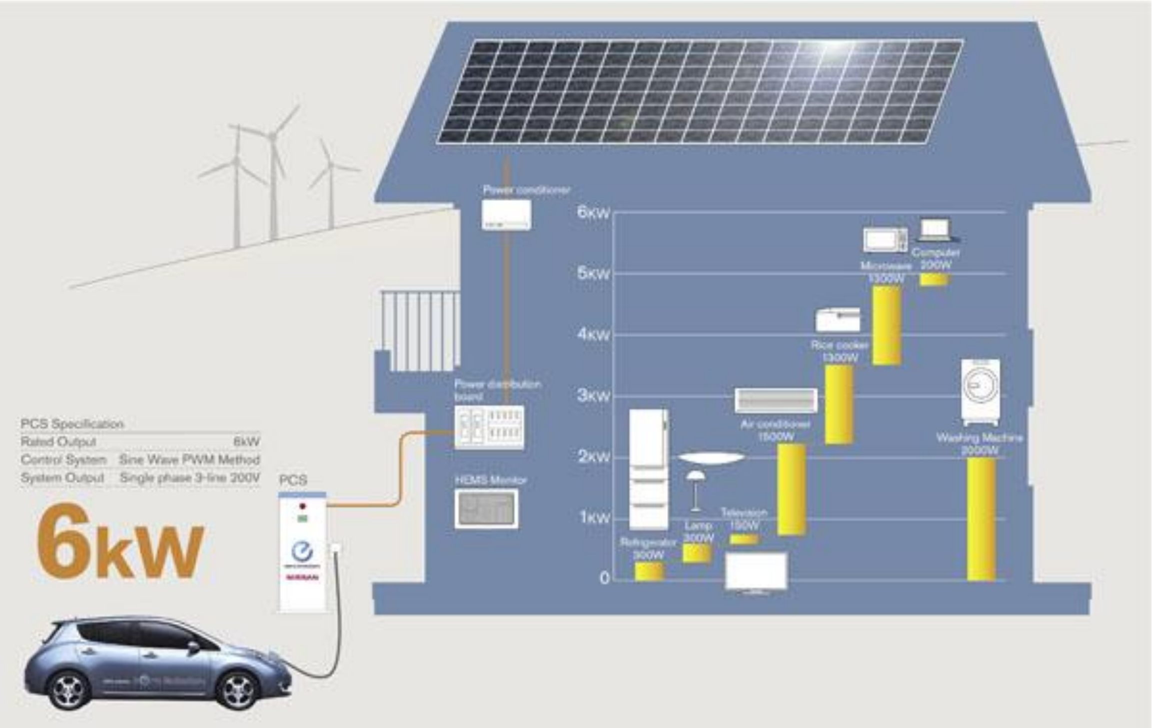
Backup Generator

- Low-cost stationary or mobile fossil fuel backup generation: gasoline, propane or natural gas
  - Stationary: 5,000 to 15,000 Watt ($5,000 to $10,000 for unit cost alone)
- Location constrained – not practical and/or safe for some locations
- No economic incentives to utilize generation for purposes other than back-up power

SOURCE: http://www.generac.com

EV Based Home Backup

- "LEAF to Home" power supply system
  - supply from batteries onboard Nissan LEAF electric vehicles (EV) to homes during an outage
  - used with the "EV Power Station" unit developed by Nichicon Corporation
- Industry first backup power supply system that can transmit the electricity stored in the large-capacity batteries of Nissan LEAF's to a residential home
- Available in Japan in 2013
- 6 kW, 24 kWh backup power
- $6,000 system on top of the cost of the vehicle



SOURCE: Nissan

Community Energy Storage (CES)

- Each unit provides ≥25 kW and 25-75 kWh at 240/120V AC
- Units are connected to secondary transformers

S&C Electric

SOURCE: S&C

Beckett Energy Systems

SOURCE: Beckett

GreenSmith

SOURCE: GreenSmith

Demand Energy

SOURCE: Demand Energy

eCamion

SOURCE: Canada Newsline

ABB

SOURCE: ABB

GS Battery

SOURCE: GSB

PowerHub

SOURCE: PowerHub & SMUD

Community Energy Storage (CES)

- Competition in distributed energy storage continues to grow

Fiamm

SOURCE: Fiamm

RedFlow

SOURCE: RedFlow

One Cycle Control

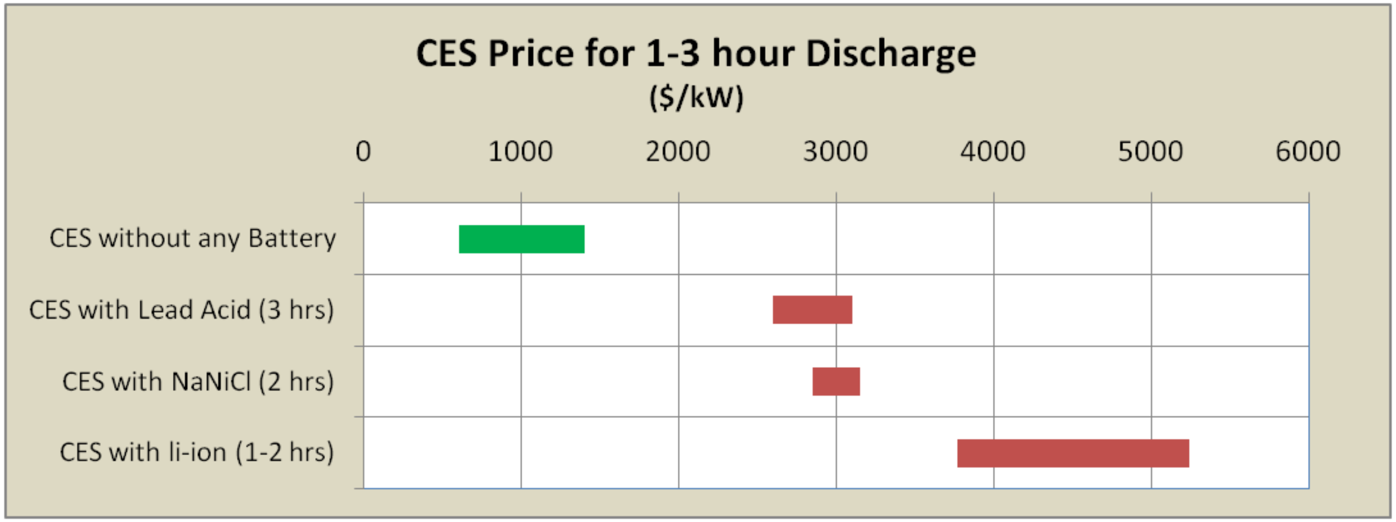
SOURCE: OCC

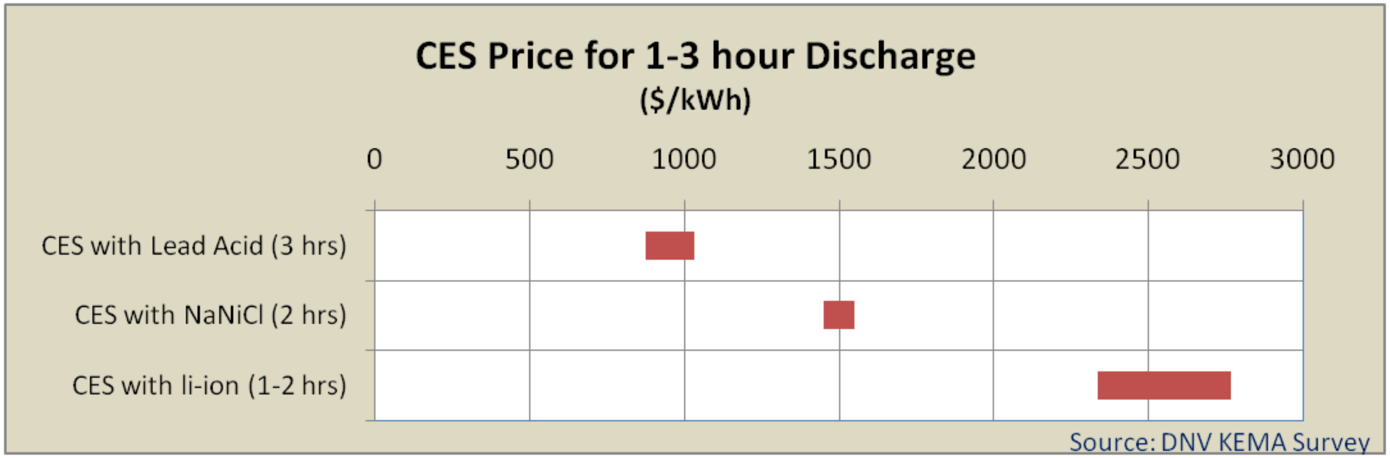
Silent Power

SOURCE: Silent Power

CES Price – 2012 and 2013 Surveys

25kW-100kW,
1-3 hours

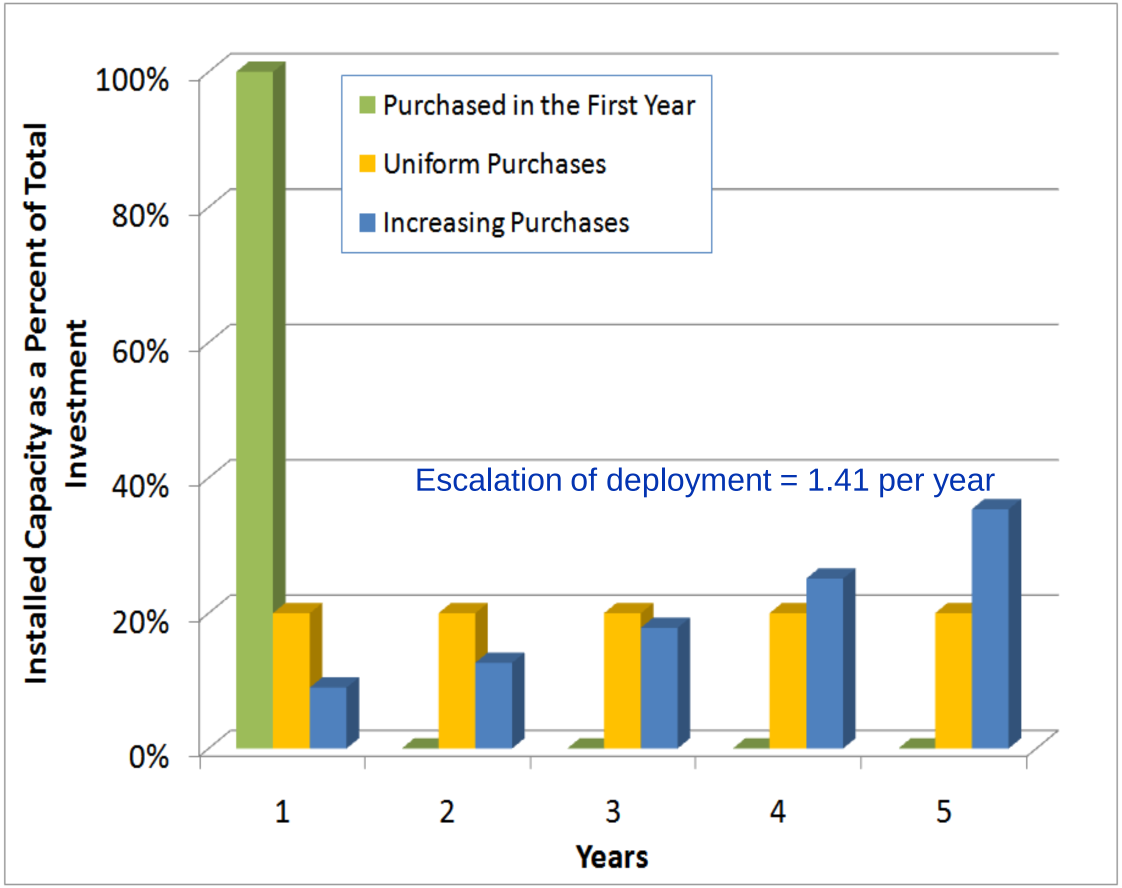




Gradual Deployment – Key to lowering the Storage Cost

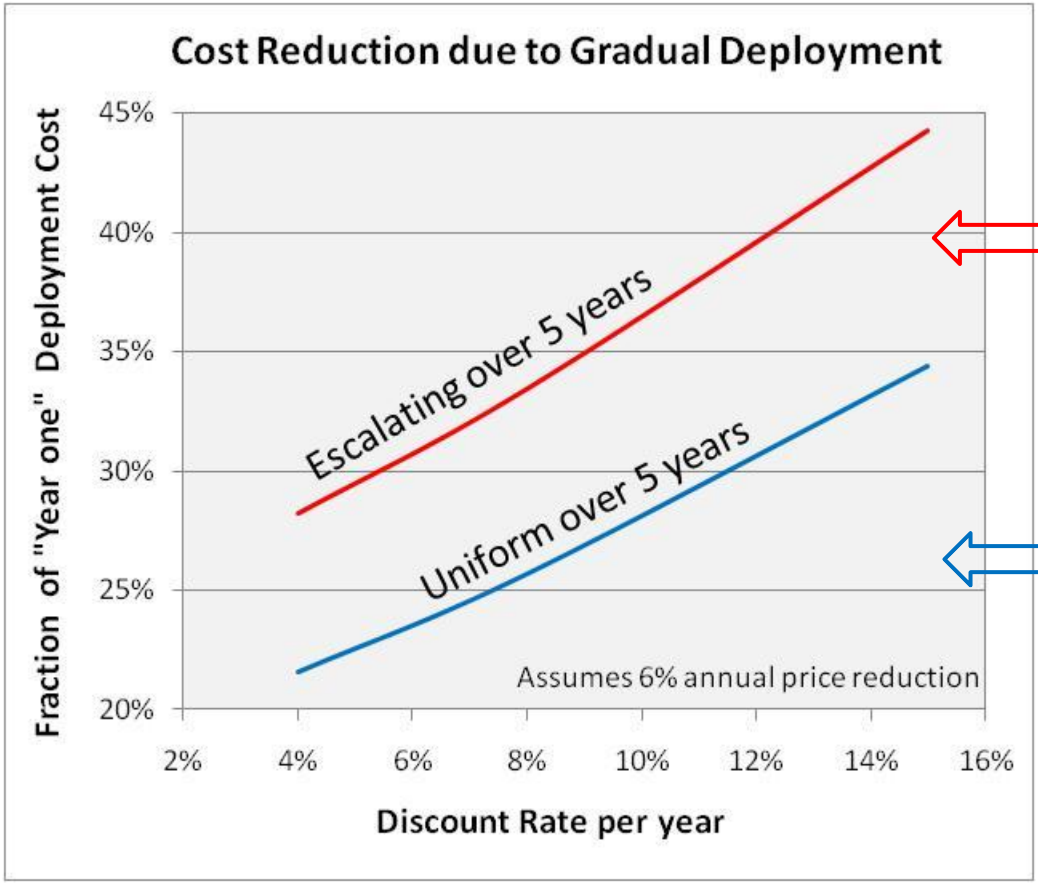
Key benefits of gradual deployment:

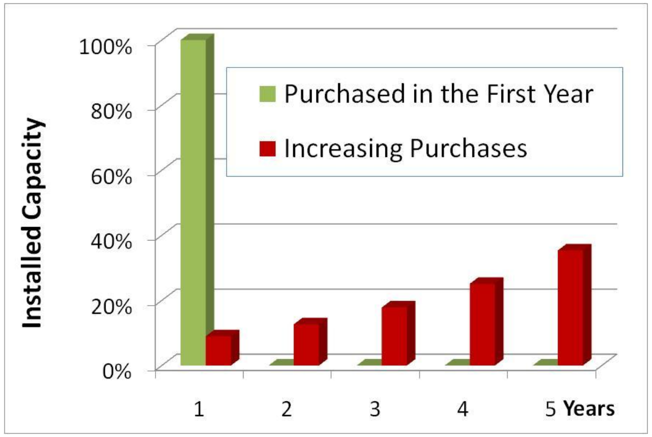
- Lower future expenditure
  - higher competition
  - commodity pricing
- Longer asset life
- Flexibility in matching
  - load growth
  - PV growth

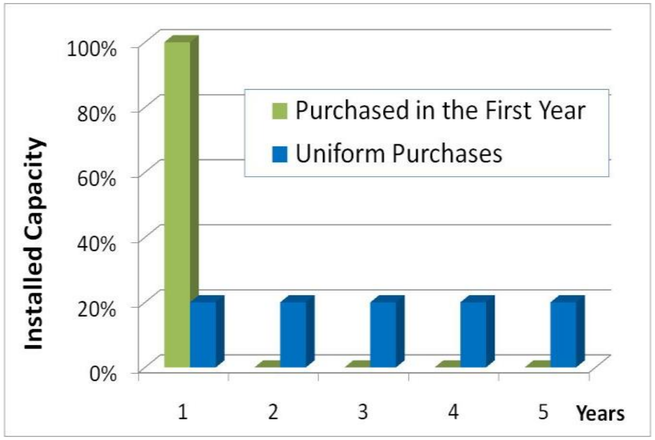


Gradual Deployment Saves 25% - 40%

Impact of Gradual Deployment on Present Value of Investment







Residential Fuel Cell

- Refrigerator sized fuel cell system hooks up to your natural gas supply
  - Fuel processor draws out hydrogen molecules
  - Electrochemical process combines hydrogen with oxygen to generate electricity
- ClearEdge Power produces a 5kW unit with heat byproduct capable of warming 750 gallons of water
  - High costs: $56,000 for fuel cell unit with installation for an existing home adding another $12,000 to $25,000
- Bloom Energy has stated future plans to develop a 1kW unit for residential market
  - Target price $3,000 with estimated 5-10 years of development required
- Panasonic's Ene-Farm 700 W home fuel cell, jointly developed with Tokyo Gas has sold over 21,000 units in Japan retails for $22,320 USD

SOURCE: ClearEdge Power

Contents

Standards Relevant to Customer-Cited PV-Energy Storage Systems

Standard	Description	Application
IEC 61850-90-7	Object Models for Photovoltaic,Storage and other DER inverters	Identifies the standard pieces of information necessary for the control of PV and Energy Storage systems. These pieces (object models) can be mapped to any communications protocol such as DNP 3.0
IEC 61850-7-420	Communications systems for Distributed Energy Resources (DER) - Logical nodes	Development of one international standard that defines the communication and control interfaces for all DER devices.[1]
IEEE 1547.8	Draft Recommended Practice for Establishing Methods and Procedures that Provide Supplemental Support for Implementation Strategies for Expanded Use of IEEE Standard 1547	Better understanding of the interactions of DR (Distributed Resource) and the grid Guidance for the increased use of DR Guidance for the use of 'smart' inverters Guidance for the integration of DR with the 'smart grid'[2]
AN2013-001	Application Note created by the DNP 3.0 Users Group Describes a standard data point configuration, set of protocol services and settings (also known as a profile) for communicating with photovoltaic (PV) generation and storage systems using the DNP3 standard3	Provides inverter manufacturers, utilities, and system integrators with standard-based methods for integration of inverter-based photovoltaic and battery storage systems with utility communication and control systems and enables the use of DNP3 to implement the full slate of common smart inverter functions identified in IEC/TR 61850-90-7.

[1] Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE
Date of Conference: 20-24 July 2008
Author(s): Cleveland, Frances M.
Xanthus Consulting Int., Boulder Creek, CA

[2] Update of the Status of IEEE 1547.8, Expanding on IEEE Standard 1547
D. L. Bassett PE, Consultant,
Senior Member, IEEE
Co-Chair IEEE 1547.8

[3] http://www.remotemagazine.com/main/news/dnp-users-group-releases-new-application-note/

Recent Standards Activities

- The NIST has created Priority Action Plan (PAP) 7 with several tasks related to the development of communication standards for PV and Energy Storage control.
  - Task 1 – define Use Cases for Distributed Energy Storage devices and applications.
  - Task 2 & 3 – development of a series of IEEE 1547 Standards revisions and extensions.
  - Task 4 – extend and harmonize object models for ES-DER devices including energy storage devices, power electronics interconnection of generation sources, and combined generation-storage devices across transmission, distribution, and consumer domains
  - Task 5 – Develop codes and test methods to ensure safe and reliable implantation of ES with the residential and commercial-building consumer domains.
- NIST PAP 12 is also underway to map IEC 61850 object models to the DNP 3.0 protocol. However, DNP3.0 is also recognized as lacking some of the capabilities necessary to carry out the entire functionality of IEC 61850 object models.
- IEC TC57 WG17 has developed the standard IEC 61850-7-420, consisting of abstract object models for four types of generators and one type of storage:
  - Diesel generators
  - Fuel cells
  - Photovoltaic systems
  - Combined heat and power (CHP)
  - Batteries

Recent Standards Activities

- The IEEE 1547.8 working group met in February, 2013. The working group is looking at a number of ways to enhance IEEE 1547 in response to new technologies and higher penetrations of distributed energy resources. A new section 4.1.7 Monitoring Provisions has been added that addresses:
  - Types of communication
  - Analog and status monitoring
  - Emergency actions
  - Autonomous modes
  - Direct management
  - Default actions or operation

Contents

C/I Customer-Sited ES, for Electric Bill Demand Charge and VAR Charge Reduction

- Commercial and Industrial (C/I) rate class tariffs typically have additional electric bill charges that residential tariffs don't: Demand charges and Power Factor (PF) penalties
- Demand charges are typically calculated on the measured peak power consumption (kW) per meter period (15-30 minutes) per billing period (month)
  - Example from ConEd's general service tariff for large C/I:

<u>Demand Delivery Charges,</u> per kW of maximum demand

Charges applicable for the months of June, July, August, and September	Low Tension Service		High Tension Service	
first 5 kW (or less)	$135.85	per month	$105.05	per month
next 95 kW	$22.34	per kW	$16.99	per kW
over 100 kW	$22.07	per kW	$16.72	per kW

- PF penalties apply when a customer's PF (a measure of relative VAR vs WATT components of customer demand) are outside of allowed limits.
  - Example from ConEd's charges, if C/I customer's PF is out of limits (0.95)

.   (4) Charge per kVar

$1.10 per kVar	applicable to Customers specified in paragraph (1)(a), (b), (c), or (d) above for billable reactive power demand. Billable reactive power demand, in kVar, shall be equal to the kVar at the time of the kW maximum demand (as defined in

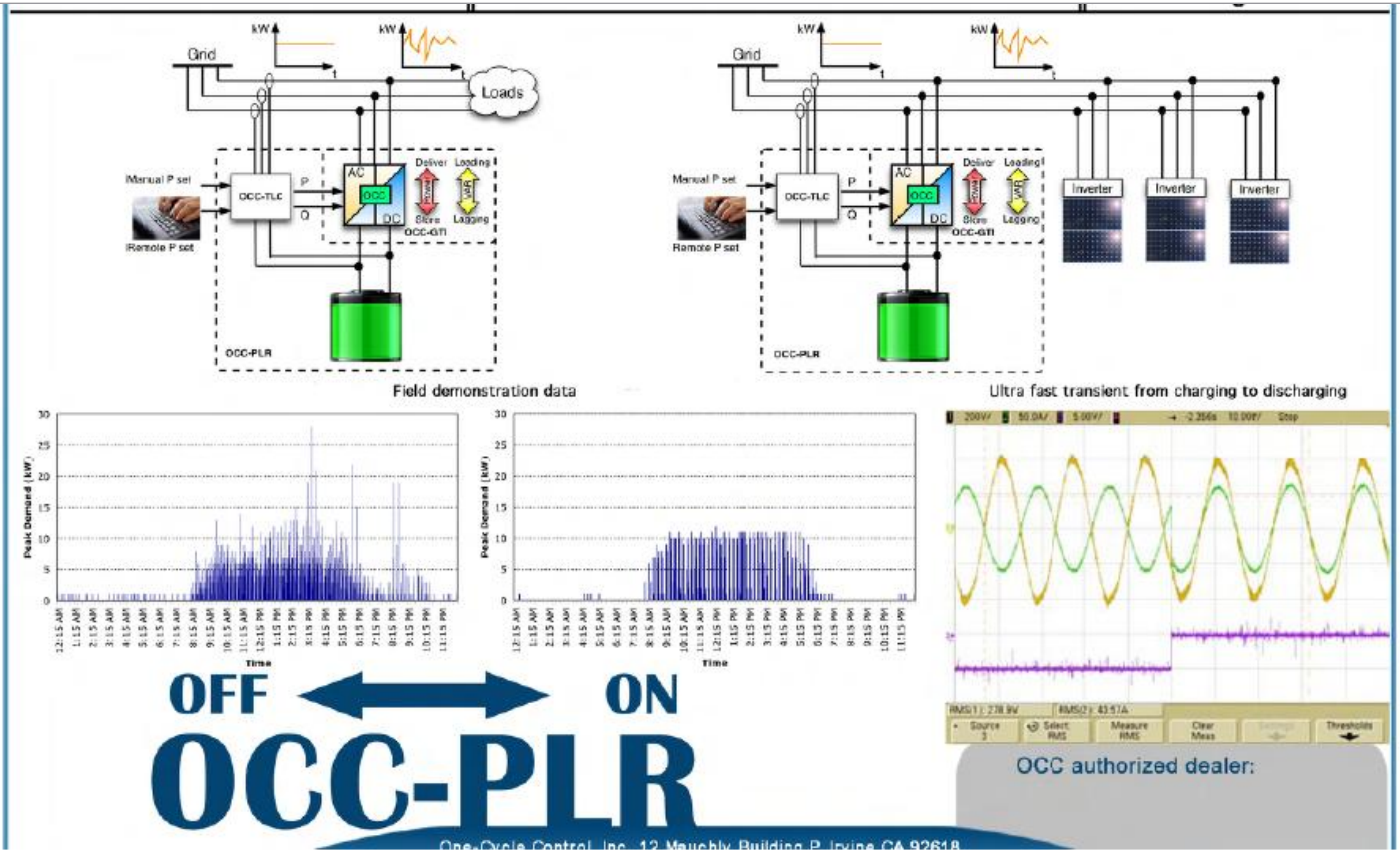
Demand Charges, ConEd’s ‘Plan Language’ Description

understanding demand billing

What Is Demand?

The term "demand' refers to the demand made by the customer upon the Company for the reserve of certain capacity. Whatever the energy requirements may be, we must maintain facilities with sufficient capacity to meet the maximum requirements of our customers. Even though these facilities may not always be used at full capacity, they are nonetheless required so that the electricity is available to customers whenever they want it. The demand charge reflects these capacity-related costs.

Example of ES Product for Demand Charge Reduction



www.onecyclecontrol.com/**OCC-PLR**-product.html

Example of ES System for Demand Charge Reduction

Examples of potential customer bill-savings benefit, for a California GS C/I rate:

One-Cycle Control, Inc. 7/13

OCC-PLR Motivation

	< 20 kWp	20-200 kWp		
	GS-1	GS-2	GS-2 Option A	GS-2 Option B
Winter ($/kWp)	-	$12	$12	$12
Summer ($/kWp)	-	$31	$12	$29 ($17 mid peak)

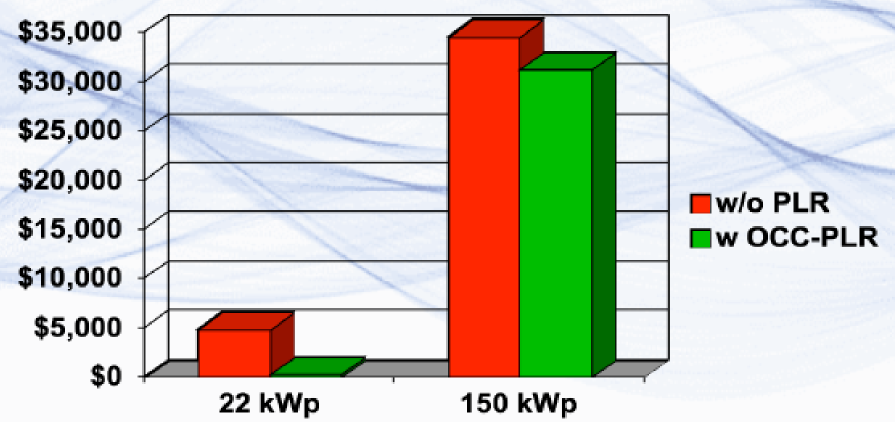
- SCE Rate Schedules & Peak Charges

gsmedley@onecyclecontrol.com 2010 © One-Cycle Control, Inc.

One-Cycle Control, Inc. 8/13

Annual Cost with / without 15kW OCC-PLR

- Customer A: 22 kWp (OCC-PLR enables GS-2 ==> GS-1)
- Customer B: 150 kWp (GS-2)



Annual Savings: $4800 $3300
(Peak kW Costs only)

gsmedley@onecyclecontrol.com 2010 © One-Cycle Control, Inc. Greg Smedley

From OCC demo and presentation to the CA Energy Comm., March 2011

Example of ES System for Demand Charge Reduction

ARISTA
PoD

Reduce electric utility demand charges with Arista's Power on Demand "Peak-Shaving" system.

WHAT IS PoD?

Arista's Power on Demand (PoD) solution is designed to reduce demand charges that can significantly increase utility bills for large users of electricity.

HOW DOES PoD WORK?

This innovative, patent-pending system is designed to utilize energy generated by wind turbines and/or solar arrays and energy stored from the grid itself to reduce peak electricity demand at consumer levels.

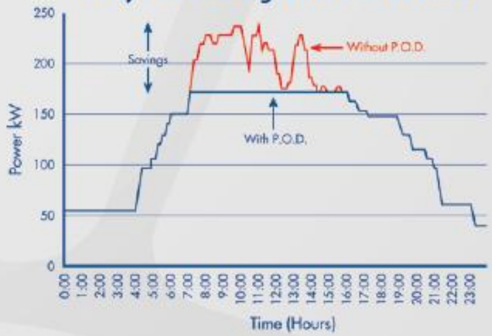
WHY PoD?

Dramatically lower your utility bills and benefit from a Return on Investment (or payback period) that no stand-alone renewable energy system can match.

WHAT IS A DEMAND CHARGE?

Large users of electricity often bear disproportionately high energy costs because they not only pay for the energy they actually use, but they are also required to pay for the right to have energy capacity available to them (whether or not they are using that capacity) at all times. This is called a "demand charge."

Daily Power Usage: kW versus Time



The chart above represents a customer's peak usage day that was used to determine their "demand charge." Arista's PoD system stores the energy captured from the WindTamer turbine and then releases the power during peak demand hours. This results in lower demand charges and utility bills for the customer. Use of the PoD system resulted in the following savings:

	Before System	Power -on- Demand
Monthly Demand Charges	$3,625	$2,360
Monthly Total	$5,967	$4,607
Annual Utility Costs	$71,607	$55,284
Annual Savings		$16,323

For a 1-4 hour duration energy storage system, the Demand Charge savings will typically exceed Energy time-shift savings

http://aristapower.com/power-od/our-systems/

Example of Demand Charge Reduction Savings Potential

Small C/I Customer with 100kW Monthly Peak Adding 'CES' BESS for 20kW Peak Demand Reduction												
ConEd Service Class 9 Rate I Demand Charge used												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Demand Charge >5kW-100kW, $/kW	17.69	17.69	17.69	17.69	17.69	23.34	23.34	23.34	23.34	17.69	17.69	17.69
Monthly peak demand reduction, kW	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20	-20
Monthly savings, $	$ (354)	$ (354)	$ (354)	$ (354)	$ (354)	$ (467)	$ (467)	$ (467)	$ (467)	$ (354)	$ (354)	$ (354)
Annual savings, $	$ **(4,698)**											
'CES' Cost 25KVA 2Hr's $2500/kW	$ 62,500											
Annual cost at 12% carrying charge, $	$ 7,500											
Years for simple payback, years	13											
'CES' Cost 25KVA 2Hr's $1500/kW	$ 37,500											
Annual cost at 12% carrying charge, $	$ **4,500** ★											
Years for simple payback, years	8											
'CES' Cost 25KVA 2Hr's $1000/kW	$ 25,000											
Annual cost at 12% carrying charge, $	$ 3,000											
Years for simple payback, years	5.3 ★											

Passes simple financial/financing screen with CES at $1,500/kW cost, w/ 12% financing

Passes simple investment/payback screen with CES at $1,000/kW cost

C/I Customer Sited ES VAR Charge Reduction Example

- ConEd example of savings from bringing customer's PF into the no-penalty zone:

.

The New Reactive-Power Charge and Mandatory Hourly Pricing

What You Need to Know Now, and Why

Reactive Power Information for Con Edison Bills

Reactive Power billing determinants to be presented on bill

Demand (kW)	3000
Power Factor	92.00%
Actual Reactive Power Demand (kVar)	1,200
Allowable Reactive Power Demand (kVar) at 95% Power Factor	1,000
Billable Reactive Power Demand (kVar)	200
Reactive Power Demand Charge @ $1.10 per billable kVar	$220.00

Reactive Power billing determinants to be presented on bill (no charge)

Demand (kW)	3000
Power Factor	97.00%
Actual Reactive Power Demand (kVar)	800
Allowable Reactive Power Demand (kVar) at 95% Power Factor	1,000
Billable Reactive Power Demand (kVar)	0
Reactive Power Demand Charge @ $1.10 per billable kVar	$0.00

- Providing VAR-support for customer-load PF correction does not consume battery capacity. It is a coincident service enabled via appropriate BESS inverter.

www.dnvkema.com

DKV KEMA Team & Contacts

- Rick Fioravanti, Principal-in-Charge
  Office: 703 631 8488
  Mobile: 703 216 7194
  Richard.Fioravanti@dnvkema.com
- Michael Kleinberg, Project Manager
  Office: 215 997 4500
  Mobile: 215 589 4178
  Michael.Kleinberg@dnvkema.com
- Ali Nourai, Dr. Eng., Team member
  Office: 614 940 7847
  Ali.Nourai@dnvkema.com
- Charlie Vartanian, Team member
  Mobile: (626) 818- 5230
  Charles.Vartanian@dnvkema.com
- Kevin Chen, Team member
  Office: (919) 256- 0839
  Kevin.Chen@dnvkema.com
- Jessica Harrison, Team member
  Office: 703 631 8493
  Jessica.Harrison@dnvkema.com

Appendix

A	Raw Load Data

Summer Average Residential Load

- Hourly kW demand / kWh energy

Load / Hour	Electric Water Heater	Central A/C	Electric Heating	Non-electric Heating (pumps, fans)	Lighting	Refrigerator	Cooking	Misc Chargers, plug loads
1	0.1896	0.7629	-	-	0.0863	0.0642	0.0063	0.0418
2	0.1402	0.6746	-	-	0.0765	0.0627	0.0045	0.0322
3	0.1078	0.5805	-	-	0.0731	0.0615	0.0043	0.0272
4	0.1209	0.5087	-	-	0.0712	0.0605	0.0059	0.0272
5	0.1307	0.4641	-	-	0.0725	0.0601	0.0109	0.0276
6	0.2244	0.4706	-	-	0.0778	0.0603	0.0172	0.0301
7	0.4925	0.4236	-	-	0.0881	0.0609	0.0232	0.0359
8	0.6116	0.5043	-	-	0.0997	0.0617	0.0285	0.0469
9	0.5763	0.5793	-	-	0.0988	0.0624	0.0323	0.0581
10	0.5870	0.7161	-	-	0.0994	0.0631	0.0365	0.0640
11	0.5328	0.8440	-	-	0.0977	0.0640	0.0406	0.0673
12	0.4590	0.9613	-	-	0.0948	0.0649	0.0428	0.0661
13	0.3793	1.0775	-	-	0.0985	0.0658	0.0431	0.0665
14	0.3584	1.2117	-	-	0.0978	0.0666	0.0438	0.0669
15	0.3113	1.3252	-	-	0.0956	0.0675	0.0517	0.0682
16	0.2756	1.4537	-	-	0.0988	0.0685	0.0689	0.0686
17	0.2941	1.5821	-	-	0.1039	0.0697	0.0876	0.0669
18	0.3529	1.5813	-	-	0.1115	0.0707	0.0983	0.0665
19	0.4291	1.5533	-	-	0.1165	0.0711	0.0941	0.0590
20	0.4365	1.4521	-	-	0.1198	0.0708	0.0766	0.0648
21	0.4134	1.3451	-	-	0.1282	0.0700	0.0538	0.0836
22	0.4518	1.2816	-	-	0.1488	0.0687	0.0339	0.0936
23	0.4243	1.1486	-	-	0.1438	0.0672	0.0202	0.0820
24	0.3196	0.9992	-	-	0.1104	0.0657	0.0114	0.0590
Daily Total:	8.6190	23.5012	-	-	2.4095	1.5687	0.9363	1.3699

Summer Peak Residential Load

- Hourly kW demand / kWh energy

Load / Hour	Electric Water Heater	Central A/C	Electric Heating	Non-electric Heating (pumps, fans)	Lighting	Refrigerator	Cooking	Misc Chargers, plug loads
1	0.2210	1.1689	-	-	0.0882	0.0656	0.0110	0.0418
2	0.1482	1.0376	-	-	0.0763	0.0643	0.0075	0.0322
3	0.1439	0.9007	-	-	0.0726	0.0631	0.0064	0.0272
4	0.1187	0.8312	-	-	0.0709	0.0622	0.0073	0.0272
5	0.1294	0.7177	-	-	0.0723	0.0616	0.0107	0.0276
6	0.1670	0.8089	-	-	0.0747	0.0615	0.0185	0.0301
7	0.2297	0.7088	-	-	0.0833	0.0618	0.0300	0.0359
8	0.3728	0.8487	-	-	0.0959	0.0625	0.0429	0.0469
9	0.5829	0.9263	-	-	0.0939	0.0633	0.0536	0.0581
10	0.7274	1.1747	-	-	0.1009	0.0642	0.0595	0.0640
11	0.7440	1.3895	-	-	0.1001	0.0652	0.0639	0.0673
12	0.6451	1.7024	-	-	0.0988	0.0664	0.0658	0.0661
13	0.5408	1.9013	-	-	0.0984	0.0674	0.0641	0.0665
14	0.4668	2.1228	-	-	0.1023	0.0683	0.0656	0.0669
15	0.3849	2.3490	-	-	0.0970	0.0691	0.0701	0.0682
16	0.3545	2.4808	-	-	0.1047	0.0699	0.0799	0.0686
17	0.3312	2.7115	-	-	0.1057	0.0708	0.0941	0.0669
18	0.3953	2.7913	-	-	0.1120	0.0716	0.0993	0.0665
19	0.4188	2.7325	-	-	0.1184	0.0718	0.0922	0.0590
20	0.4629	2.5596	-	-	0.1207	0.0716	0.0754	0.0648
21	0.5088	2.5702	-	-	0.1284	0.0709	0.0527	0.0836
22	0.4862	2.4678	-	-	0.1457	0.0698	0.0326	0.0936
23	0.3956	2.3139	-	-	0.1393	0.0686	0.0188	0.0820
24	0.2956	2.1315	-	-	0.1089	0.0674	0.0100	0.0590
Daily Total:	9.2715	41.3476	-	-	2.4095	1.5989	1.1321	1.3699

Winter Average Residential Load

- Hourly kW demand / kWh energy

Load / Hour	Electric Water Heater	Central A/C	Electric Heating	Non-electric Heating (pumps, fans)	Lighting	Refrigerator	Cooking	Misc Chargers, plug loads
1	0.1890	-	1.1305	0.0707	0.0966	0.0505	0.0100	0.0418
2	0.1443	-	1.2599	0.0787	0.0886	0.0492	0.0088	0.0322
3	0.1173	-	1.3724	0.0858	0.0846	0.0486	0.0094	0.0272
4	0.0903	-	1.6124	0.1008	0.0829	0.0484	0.0113	0.0272
5	0.1483	-	2.2526	0.1408	0.0849	0.0486	0.0162	0.0276
6	0.2979	-	2.8510	0.1782	0.0971	0.0495	0.0236	0.0301
7	0.6609	-	3.9911	0.2494	0.1257	0.0506	0.0299	0.0359
8	0.9366	-	4.1386	0.2587	0.1556	0.0513	0.0345	0.0469
9	0.8030	-	3.5866	0.2242	0.1375	0.0517	0.0360	0.0581
10	0.6965	-	2.9332	0.1833	0.1230	0.0514	0.0360	0.0640
11	0.5751	-	2.1672	0.1355	0.1146	0.0511	0.0381	0.0673
12	0.4976	-	1.8618	0.1164	0.1094	0.0513	0.0413	0.0661
13	0.4319	-	1.7914	0.1120	0.1089	0.0516	0.0455	0.0665
14	0.3832	-	1.6191	0.1012	0.1048	0.0520	0.0525	0.0669
15	0.3353	-	1.7216	0.1076	0.1045	0.0527	0.0656	0.0682
16	0.3062	-	1.7858	0.1116	0.1141	0.0537	0.0884	0.0686
17	0.3554	-	2.7075	0.1692	0.1368	0.0551	0.1148	0.0669
18	0.4867	-	2.7847	0.1740	0.1828	0.0567	0.1276	0.0665
19	0.6131	-	2.9045	0.1815	0.2100	0.0578	0.1213	0.0590
20	0.6188	-	2.5649	0.1603	0.2062	0.0583	0.0988	0.0648
21	0.5160	-	2.4305	0.1519	0.2037	0.0578	0.0664	0.0836
22	0.4849	-	2.0836	0.1302	0.1888	0.0566	0.0404	0.0936
23	0.4291	-	1.6074	0.1005	0.1570	0.0548	0.0241	0.0820
24	0.2927	-	1.2059	0.0754	0.1188	0.0527	0.0133	0.0590
Daily Total:	10.4103	-	54.3643	3.3978	3.1371	1.2618	1.1539	1.3699

Winter Peak Residential Load

- Hourly kW demand / kWh energy

Load / Hour	Electric Water Heater	Central A/C	Electric Heating	Non-electric Heating (pumps, fans)	Lighting	Refrigerator	Cooking	Misc Chargers, plug loads
1	0.2225	-	1.6273	0.1017	0.1090	0.0518	0.0135	0.0418
2	0.1595	-	1.8954	0.1185	0.0951	0.0503	0.0161	0.0322
3	0.1169	-	2.1659	0.1354	0.0859	0.0495	0.0177	0.0272
4	0.0895	-	2.5581	0.1599	0.0823	0.0494	0.0185	0.0272
5	0.1151	-	3.5937	0.2246	0.0806	0.0496	0.0173	0.0276
6	0.1297	-	4.3168	0.2698	0.0832	0.0506	0.0220	0.0301
7	0.1789	-	5.5379	0.3461	0.0919	0.0518	0.0341	0.0359
8	0.3058	-	5.6362	0.3523	0.1076	0.0525	0.0495	0.0469
9	0.5173	-	5.2515	0.3282	0.1224	0.0528	0.0659	0.0581
10	0.7655	-	4.2955	0.2685	0.1354	0.0524	0.0768	0.0640
11	0.9335	-	3.3096	0.2068	0.1323	0.0519	0.0825	0.0673
12	0.8661	-	2.9292	0.1831	0.1265	0.0521	0.0845	0.0661
13	0.7936	-	2.7900	0.1744	0.1335	0.0526	0.0848	0.0665
14	0.6675	-	2.4433	0.1527	0.1287	0.0532	0.0913	0.0669
15	0.6085	-	2.6214	0.1638	0.1252	0.0540	0.1006	0.0682
16	0.4896	-	2.6211	0.1638	0.1382	0.0552	0.1149	0.0686
17	0.5074	-	3.5100	0.2194	0.1431	0.0566	0.1328	0.0669
18	0.5794	-	3.9873	0.2492	0.1835	0.0578	0.1335	0.0665
19	0.6068	-	4.1400	0.2588	0.2027	0.0587	0.1170	0.0590
20	0.5647	-	3.7107	0.2319	0.1974	0.0589	0.0901	0.0648
21	0.4862	-	3.4934	0.2183	0.1933	0.0585	0.0565	0.0836
22	0.4195	-	3.0016	0.1876	0.1729	0.0576	0.0329	0.0936
23	0.3676	-	2.6668	0.1667	0.1530	0.0560	0.0221	0.0820
24	0.2815	-	1.9002	0.1188	0.1135	0.0538	0.0174	0.0590
Daily Total:	10.7728	-	80.0028	5.0002	3.1371	1.2876	1.4925	1.3699