EAC
ELECTRICITY ADVISORY COMMITTEE

Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid

A Report by
The Electricity Advisory Committee
December 2008

ELECTRICITY ADVISORY COMMITTEE

ELECTRICITY ADVISORY COMMITTEE MISSION

The mission of the Electricity Advisory Committee is to provide advice to the U.S. Department of Energy in implementing the Energy Policy Act of 2005, executing the Energy Independence and Security Act of 2007, and modernizing the nation's electricity delivery infrastructure.

ELECTRICITY ADVISORY COMMITTEE GOALS

The goals of the Electricity Advisory Committee are to provide advice on:

- Electricity policy issues pertaining to the U.S. Department of Energy
- Recommendations concerning U.S. Department of Energy electricity programs and initiatives
- Issues related to current and future capacity of the electricity delivery system (generation, transmission, and distribution, regionally and nationally)
- Coordination between the U.S. Department of Energy, state, and regional officials and the private sector on matters affecting electricity supply, demand, and reliability
- Coordination between federal, state, and utility industry authorities that are required to cope with supply disruptions or other emergencies related to electricity generation, transmission, and distribution

ENERGY INDEPENDENCE AND SECURITY ACT OF 2007

The Energy Storage Technologies Subcommittee of the Electricity Advisory Committee was established in March 2008 in response to Title VI, Section 641(e) of the Energy Independence and Security Act of 2007 (EISA).

This report fulfills requirements of EISA Title VI, Section 641(e)(4) and (e)(5).

Section 641(e)(4) stipulates that “No later than one year after the date of enactment of the EISA and every five years thereafter, the Council [i.e., the Energy Storage Technologies Subcommittee, through the Electricity Advisory Committee], in conjunction with the Secretary, shall develop a five-year plan for integrating basic and applied research so that the United States retains a globally competitive domestic energy storage industry for electric drive vehicles, stationary applications, and electricity transmission and distribution.”

EISA Section 641(e)(5) states that “the Council shall (A) assess, every two years, the performance of the Department in meeting the goals of the plans developed under paragraph (4); and (B) make specific recommendations to the Secretary on programs or activities that should be established or terminated to meet those goals.”

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Letter from the Chair

December 2008

On behalf of the members of the Electricity Advisory Committee (EAC), I am pleased to provide Congress and the U.S. Department of Energy (DOE) with this report, ***Bottling Electricity*: *Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid.*** This report recommends policies that the U.S. Department of Energy (DOE) should consider as it develops and implements an energy storage technologies program, as authorized by the Energy Independence and Security Act of 2007.

The recommendations here were developed through a process undertaken in 2008 by the Electricity Advisory Committee. The members of the Electricity Advisory Committee represent a broad cross-section of experts in the electric power delivery arena, including representatives from industry, academia, and state government. I want to thank ***Brad Roberts***, Chair, Electricity Storage Association and Power Quality Systems Director, S & C Electric Company for his leadership as Chair of the EAC Energy Storage Technologies Subcommittee and to the EAC members who served on the Subcommittee. Thanks also go to ***Kevin Kolevar***, Assistant Secretary for Electricity Delivery and Energy Reliability, U.S. Department of Energy and to ***David Meyer***, Senior Policy Advisor, DOE Office of Electricity Delivery and Energy Reliability and Designated Federal Officer of the Electricity Advisory Committee.

The members of the Electricity Advisory Committee recognize the vital role that the U.S. Department of Energy can play in modernizing the nation's electric grid. These recommendations provide options for the U.S. Department of Energy to consider as it develops and deploys energy storage technologies, policies, and programs to help ensure a 21st century electric power system. This report and its recommendations also fulfill the requirements in Section 641(e)(5)(B) of the Energy Independence and Security Act of 2007.

Sincerely,

Linda Stuntz, Chair
Electricity Advisory Committee

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Special thanks to ***Peggy Welsh***, Senior Consultant, Energetics Incorporated, and to ***Amanda Warner***, Energy Policy Analyst, Energetics Incorporated, for their tireless support of the Electricity Advisory Committee.

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Chapter 1
Overview

The ability to store energy in cell phones, personal digital assistants such as Blackberrys, and other handheld devices has become an essential component of business and daily life for consumers in the United States. The rapid advancement of communications and information processing technologies illustrates how small-scale energy storage technologies (e.g., batteries in handheld devices) can become a critical platform for the reliable performance of tools used for everyday life. The same information and communications technologies will be the primary drivers in transforming the U.S. electric power grid into a more reliable, secure, and efficient network capable of dealing with massive changes over the next two decades. It is necessary to evaluate what type and amount of energy storage technology will be needed to facilitate the electric power delivery system transformation that will support this growth and to deploy a Smart Grid. (A detailed discussion of the benefits of a Smart Grid is available in the Electricity Advisory Committee [EAC] report, *Smart Grid: Enabler of the New Energy Economy*, December 2008.)

1.1 Background

The first application of large-scale energy storage (31 megawatts [MW]) in the United States occurred in 1929, when the first pumped hydroelectric power plant was placed into service. Pumping water from a lower elevation to a higher elevation was the most practical way to store large amounts of energy that could then be released during periods of high, or peak, demand. These power plants are still used to help manage grid frequency and provide clean reserve generation, known as ancillary services. During a 30-year period from the late 1950s to the late 1980s, approximately 19,500 MW of pumped hydroelectric storage facilities were brought into service in the United States.[1] By 2000, about 3% of the total power delivered by the nation's grid (18,000 MW) was supplied through these energy storage facilities.[2] Because of the need for significant elevation changes in pumped hydroelectric plan designs, the number of environmentally acceptable sites for future pumped hydroelectric facilities is very limited. The siting of new plants will face the same objections that the siting of new transmission lines faces today. Nevertheless, planning is underway to add new pumped hydroelectric power plants to the U.S. grid.

Currently, the energy storage technology receiving the most attention for use in large-scale energy storage is compressed air energy storage (CAES). A 115 MW CAES demonstration power plant was placed in service in the early 1990s and has proven to be effective, although long-term costs without research and development (R&D) and demonstration support remain to be evaluated. Underground formations, such as salt domes and depleted gas fields, can be adapted for use with CAES technology. These systems appear to be practical in a power range from above 100 MW up to several thousand MW. A major energy research institute has proposed two pilot plants to member utilities. One municipal utility

[1] Energy Information Administration, *Inventory of Electric Utility Power Plants in the United States 2000*, http://www.eia.doe.gov/cneaf/electricity/ipp/ipp_sum.html (accessed December 4, 2008).
[2] Ibid.

power plant is under development in Iowa, along with other proposals from commercial developers.[3]

The most common form of energy storage in use today is based on lead-acid batteries. The rapid growth of the information age has spawned the construction of data centers to support the Internet and communications centers. These facilities are sensitive to power supply disruptions, so large battery-powered protection systems have been and will continue to be deployed to achieve a high level of protection. Powering these types of loads currently accounts for over 1.5% of the total utility power consumption in the United States.[4]

Total consumption of lead-acid batteries for commercial, industrial, and automotive use in the United States is currently $2.9 billion per year and is growing at an annual rate of 8%.[5] In the past, use of lead-acid batteries for utility applications such as peak shaving was tested, but the economics and life cycle characteristics were not ideal for the daily cycling capabilities desired in utility applications.

Lithium-ion battery use is growing rapidly. Potential use of lithium-ion batteries for high-power transportation applications has helped drive sales in the United States to $1billion in 2007, with future growth rates projected at 50–60% per year.[6] The ability of lithium-ion batteries to economically serve electric utility applications has not yet been demonstrated, except for some ancillary services provisions to independent system operators (ISOs).

There are several other electrochemical technologies in use for electric backup power applications. These battery technologies are also being investigated or deployed for utility-scale applications. Battery technologies include sodium sulfur, zinc-bromine, vanadium redox, and polysulfide-bromide redox flow batteries, among others. The sodium sulfur battery is a technology widely used in Japanese utilities and is being deployed in the United States today. The zinc-bromine battery is currently in use in the United States.

Nickel-cadmium (Ni-Cad) and Nickel metal hydride (Ni-MH) batteries, common to power tools, have also found applications in backup electric power applications but are being surpassed by other technologies for cost and energy-density reasons in utility applications.

Additionally, there are other energy storage technologies with potential performance and cost advantages, including direct air compression via wind turbines and underground pumped hydroelectric facilities.

The pressing need for better energy storage technologies for electric-drive vehicle applications and the potential advantages of energy storage for utility applications have provided incentives for R&D and venture capital funding in new energy storage technologies. However, the potential for even higher-performance (energy density) or lower-cost electro-technologies, based simply on analysis of the periodic table of elements, is very large. If battery technology is to be dramatically improved, there is still a need for federal R&D in basic electrochemistry to identify the combinations of chemical compounds that have the highest potential for use in energy storage devices.

1.2 Benefits of Deploying Energy Storage Technologies

The nation must continue to pursue all alternatives for the continued availability of highly reliable and inexpensive electric power supply. These alternatives include the deployment of renewable energy resources, nuclear power, clean coal generation, and other generation resources; the transmission upgrades necessary to interconnect these resources with load; and various conservation and demand response / load management programs. The United States should also consider energy storage technologies as a strategic choice that allows for optimum use of existing and new resources of all kinds. Energy storage technologies are not an alternative to any particular resource decision; rather, they are a valuable adjunct to all resources, and they will allow increased capacity to be derived from any given quantity of physical resources.

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[3] Holst, Ken, "Iowa Stored Energy Park" (presentation, U.S. Department of Energy Storage Program Peer Review, September 2008).

[4] Koomey, Jonathan G., *Estimating the total power consumption by servers in the U.S. and the world*, (Lawrence Berkeley National Laboratory, February 2007).

[5] Buchmann, Isidor, "Battery Statistics," Freedonia Battery University, http://www.batteryuniversity.com.

[6] Lux Research, *Energy Storage for Electric Vehicles* (New York: Lux Research, October 2008), http://www.luxresearchinc.com.

There are many benefits to deploying energy storage technologies into the nation's grid. Energy storage can provide:

1. A means to improve grid optimization for bulk power production
2. A way to facilitate power system balancing in systems that have variable or diurnal renewable energy sources
3. Facilitation of integration of plug-in hybrid electric vehicle (PHEV) power demands with the grid
4. A way to defer investments in transmission and distribution (T&D) infrastructure to meet peak loads (especially during outage conditions) for a time
5. A resource providing ancillary services directly to grid/market operators

Depending upon the principal application of the energy storage technology and the contributing institution, energy storage can be seen as a generation, transmission, distribution, or end-user resource. When the energy storage technology is connected to the grid either at a substation or in conjunction with a generation resource, the labeling and identification of it as one asset class or another inevitably gets entangled with cost allocation (and revenue accrual) issues. Depending upon the technology and its performance characteristics, it may be most effective if seen as a "system" resource, one that can be used optimally to improve reliability and economics without regard to being classified as one resource type or another.

1.3 Distributed vs. Bulk Power Energy Storage

Pumped hydroelectric and CAES technologies are considered bulk power energy storage systems. In contrast, new classes of batteries have been developed that are considered suitable for smaller applications and are referred to as "distributed" utility storage systems. (In this context, the term "distributed" is used as a differentiation from "large centralized" energy storage technologies, analogous to large centralized power plants.) The term distributed energy storage means deployment of these devices close to load centers, transmission system points of reinforcement, or renewable generation sources, typically in or near utility substations. In other contexts, the term "distributed" denotes location on distribution feeder circuits or at consumer premises behind the meter.

The two main classes of batteries in this distributed energy storage category are flow batteries and high-temperature batteries such as sodium sulfur (NaS) and sodium nickel chloride (NaNiCl) batteries. Industry experts have found that, unlike lead-acid batteries, these devices can cycle on a daily basis and have useful operating lives in the range of 10 to 20 years. These systems can be designed for charge/discharge durations up to eight hours per day. All of these devices are scaled chemistries with no emissions and quiet operation.

Flow battery technology utilizes an active element in a liquid electrolyte that is pumped through a membrane similar to a fuel cell to produce an electrical current. The system's power rating is determined by the size and number of membranes, and the runtime (hours) is based on the gallons of electrolyte pumped through the membranes. Pumping in one direction produces power from the battery, and reversing the flow charges the system.

High-temperature batteries operate above 250ºC and utilize molten materials to serve as the positive and negative elements of the battery. These chemistries produce battery systems with very high power densities that serve well for storing large amounts of energy. The NaS battery is currently being deployed in the United States by several large utilities in demonstration projects. The NaNiCl battery systems are utilized in Europe primarily for electric bus applications.

Other energy storage devices such as flywheels and supercapacitors are being applied for power quality applications and frequency regulation for utilities and other load-balancing uses to reduce emissions from diesel generator-powered devices such as port cranes. For these systems, energy storage is measured in minutes.

The one energy storage technology poised for both utility and automotive use in PHEVs is lithium-based battery technologies. Lithium-ion batteries dominate the portable electronics market, and variations in their chemistries are yielding higher-power designs with improved cycling capability. Current projections indicate that PHEVs with these new batteries will be on the road by 2010 or 2011. The acceptance of these vehicles and the ensuing rate of adoption by the public will determine the timing of their impact on the overall power demand of the utility grid. Assuming that most charging of PHEVs occurs at night, the relative impact on the grid over time should be positive in conjunction with the anticipated significant growth of wind energy. Uncontrolled daytime or early evening charging by PHEVs, by contrast, could pose challenges to system economics and capacity, as the extra demand could increase congestion or peak use.

Full integration of new sources of energy demand coupled with the overall increase in electricity use is a major challenge facing the designers of the U.S. grid of the future. Energy storage technologies need to be examined closely to understand where storage can add value to the overall electricity infrastructure. Examples of the value of energy storage technologies could include capital deferral, energy maintenance during islanding (continuing to power a portion of a grid independently from the utility source), and better utilization of generation in coordination with the variable output nature of renewable energy generation.

The ratio of storage energy capacity to charge/discharge power rating, or the duration of the energy storage that is required, varies depending upon the application and favors different technologies accordingly. Energy density, cost, efficiencies, and environmental concerns are additional factors that affect the applicability of different technologies to different purposes. The electric vehicle application drives most R&D for advanced materials today, but it should be noted that it is also the most demanding application and thus the one that justifies higher costs. In the long term, the best energy storage technologies for utility-scale applications may be different from those used for electric-drive vehicles.

1.4 How Much Energy Storage Would Be Beneficial?

Determining the amount and overall value of energy storage that should be added to the grid begins with an examination of the marginal cost of generating electricity. The U.S. electric power industry runs at very low capacity factors—perhaps as low as 40%. (This means that the average level of production is only 40% of the peak capacity that is installed and theoretically available.)[7] This capacity has been acceptable to the industry because generation resources have traditionally been more cost-effective sources of capacity than energy storage resources. The growth of renewable energy will likely lead to even lower capacity factors for traditional generation sources.

Many of the drivers for a Smart Grid are based on a desire to improve capacity factors by shifting the demand curve through either incentives or controls. Beyond some point that remains to be determined, there is likely to be some public resistance to the degree of load shifting (and high real-time prices) entailed in the deployment of demand response / load management programs. Energy storage technology offers another path to help balance the system as a means to adapt production to demand while improving capacity factors. As such, the deployment of energy storage technologies may be more acceptable politically than other types of infrastructure upgrades and potentially less disruptive to the U.S. economy and society. This outcome will provide powerful motivation to invest in energy storage technologies R&D.

Another positive aspect of the implementation of energy storage technologies is the potential to capture and store electricity from wind energy when there is a lack of transmission infrastructure. For example, wind curtailment has already become common in Texas because of a lack of transmission capacity to move that power from western Texas to load centers in other parts of the state. In many regions, including Texas, transmission projects are moving forward to better connect wind power plants with load centers, although energy storage technologies may have potential value in the interim.[8] In addition, as wind power deployment increases, wind output may begin to exceed electricity demand during certain times of the year, which would necessitate curtailment. While Texas is moving forward with a $5 billion investment in new transmission capacity to ameliorate this problem, it could take up to 5 years to bring this new

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[7] U.S. Department of Energy, Energy Information Agency, "Energy Basics 101 Electricity Basic Statistics," http://www.eia.doe.gov/basics/quickelectric.html (accessed December 12, 2008).

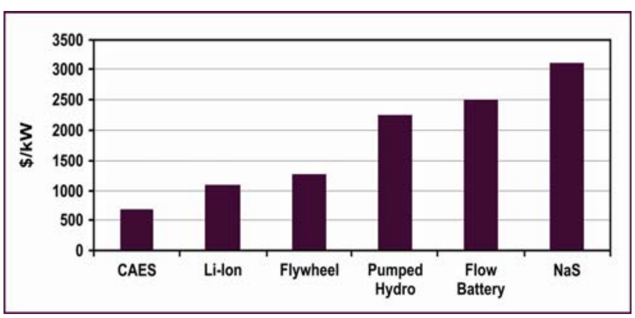
[8] Dan Woodfin, *CREZ Transmission Optimization Study Summary* (Electric Reliability Council of Texas Board of Directors Meeting, April 15, 2008), PowerPoint slides. http://www.ercot.com/meetings/board/keydocs/2008/B0415/Item_6_-_CREZ_Transmission_Report_to_PUC_-_Woodfin_Bojorquez.pdf.

transmission infrastructure online. This problem may also be aggravated by inflexible nuclear and coal power plants that have limited ability to decrease their output, given the difficulty of powering up or powering down these large baseload facilities.

The July 2008 U.S. Department of Energy (DOE) report *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply* discusses the scenario in which integration of 300 gigawatts (GW) of wind energy into the U.S. grid is achieved.[9] To deal with the variability of the wind energy output, approximately 50 GW of new peaking plant gas turbines would be used to supplement or compensate for the variability of the wind power's output. Energy storage could serve a portion of this needed capacity.

In analyzing energy storage alternatives, Figure 1-1 shows the current cost estimates for various types of energy storage technologies available today. With the exception of CAES, all other forms of energy storage have no emissions associated with the energy discharge cycle. CAES systems burn a mixture of compressed air and natural gas to generate power. CAES technology requires further evaluation and is highly dependent upon the cost of preparing underground caverns or other geophysical domains for compressed air storage. CAES technology also requires fuel costs for discharging, which are not captured in Figure 1-1. If the system operated on compressed air alone, the costs per kilowatt (kW) would be approximately three times greater.

Figure 1-1: Current Energy Storage Technologies Cost Estimates



Source: Figure created for *Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid* by EAC Energy Storage Technologies Subcommittee 2008

Energy storage technology types can be divided into two categories based on their economically practical duration: those with hours of runtime, and those with minutes of runtime. Currently, flywheels and lithium-ion batteries rated for smaller amounts of energy are appearing in the grid today for ancillary service use such as frequency regulation. All other energy storage technologies can provide hours of energy runtime in addition to use in ancillary services such as frequency regulation. One issue that needs attention is the development of lower-cost energy storage systems in the 1–4 hour runtime range through product improvements in existing technologies or new technologies.

1.5 Objectives of this Report

The objectives of this report are to provide the Secretary of Energy with the Electricity Advisory Committee's proposed five-year plan and recommendations for integrating basic and applied research on energy storage technology applications for electric-drive vehicles, stationary applications, and electricity transmission and distribution, as mandated by Subtitle D, Section 641(c)(4) of the Energy Independence and Security Act of 2007, and to provide an analysis of the potential for energy storage technology deployment in the coming years.

The report is divided into three major sections:

1. Regulatory issues and potential barriers to adding energy storage
2. Energy storage growth in PHEVs
3. Meeting the mandates of the Energy Independence and Security Act of 2007

Each of the issues is presented in terms of the specific areas of concern and the recommended actions that need to occur. Each topic is presented with a set of goals and metrics to measure progress. Where possible, goals and associated timelines are provided based on near-term goals (3–5 years), mid-term goals (5–12 years), and long-term goals (2020 and beyond).

[9] U.S. Department of Energy, *20% Wind Energy by 2030* (Washington, DC: U.S. Department of Energy, 2008), http://www.20percentwind.org/20percent_wind_energy_report_revOct08.pdf.

Chapter 2 Energy Storage Technology Applications

Electricity has traditionally been used at the time at which it is generated. It is not often stored, despite the fact that energy storage would allow for the optimization of power generation. Currently, the United States has adapted generation to match peak load, resulting in very low capacity factors for the electric power industry, as much of the capacity is used infrequently to meet peak demand. The shift in generation resources from fossil fuels to renewable energy resources as a source of electric power will aggravate this low capacity factor because wind power, in particular, is often strongest at times when electric demand is far from peak. Used to levelize the production/demand mismatch over various time domains, energy storage technologies have a number of generation applications. In addition, storage also has transmission applications that improve transmission capacity and reliability.

2.1 Benefits of Deploying Energy Storage Technologies

Benefits to Transmission and Distribution

Energy storage applications may offer potential benefits to the transmission and distribution (T&D) system because of the ability of modern power electronics, and some electrochemistries, to change from full discharge to full charge, or vice versa, extremely rapidly. These characteristics enable energy storage to be considered as a means of improving transmission grid reliability or increasing effective transmission capacity. At the distribution level, energy storage can be used in substation applications to improve system power factors and economics and can also be used as a reliability enhancement tool and a way to defer capital expansion by accommodating peak load conditions.

Energy storage can also be used to alleviate diurnal or other congestion patterns and, in effect, store energy until the transmission system is capable of delivering the energy to the location where it is needed.

Benefits to Renewable Energy Resources

One area in which energy storage technologies could provide great benefits is in conjunction with renewable energy resources. By storing energy from variable resources such as wind and solar power, energy storage could provide firm generation from these units, allow the energy produced to be used more efficiently, and provide ancillary transmission benefits.

Benefits to End-Use Consumers

At the end-use level, energy storage technologies can be used to capture distributed renewable generation—photovoltaic solar or wind power—and store it until it is needed, both for off-grid and grid-connected applications. As such, end-user energy storage technology applications also have the potential benefit of improving grid utilization, especially if end-user energy storage can be coordinated with utility operations. One example of such coordination is the use of energy storage in large commercial buildings to allow peak shaving and demand response / load management to occur without reducing actual building services and heating, ventilation, and air conditioning (HVAC).

A potential benefit of an end-user energy storage technology is vehicle-to-grid (V2G) technology, whereby plug-in hybrid electric vehicles (PHEVs), with the added capability of discharging back to the grid, are used to improve grid utilization, levelize demand, and improve reliability. Because expectations for PHEV deployment are so high, there is great interest in the electric power utility industry about the potential for V2G to provide many of the benefits of energy storage at the distribution and end-user level.

Benefits to Niche Applications

There are also high-value benefits to niche energy storage applications associated with specific end-use sectors. An example of such a niche application is the use of energy storage technology in commuter rail stations to provide accelerating power to trains where it is needed and thus minimize losses associated with track catenary distribution. Other specific industrial applications will be developed as megawatt-scale energy storage technology becomes proven and economic and that will provide added benefits of energy storage technologies.

2.2 Generation Applications

This section further discusses the potential benefits of energy storage across different infrastructure and time domains and gives some indications of the performance characteristics required by each application and the estimated economic gains.

Table 2-1 summarizes generation domain applications and their benefits. In addition, some general comments regarding generation applications are provided for increased understanding.

Many of the generation services that are potential energy storage applications are existing energy market-defined products (e.g., ancillary services and balancing energy), and as such, market costs for these services are readily available. Where markets are not deregulated, the amount of energy storage capacity that could be used is roughly linked to system or generator sizes. In most cases, the overall economic benefits can be used to finance energy storage technology projects via normal market mechanisms.

When benefits are described as alleviating conventional generation capacity to provide energy, it is because the provision of an ancillary service requires that the generator operate at less than full capacity. Thus, the owner of that generator incurs an opportunity cost in that the margins on production are decreased; this cost is a large part of the pricing demanded for ancillary provision, especially at peak load. In some cases, generating units that are not “in the market” and would be uneconomical are used to provide ancillary services, generally at higher prices. Replacing these units with energy storage technologies would reduce these costs and the associated emissions from these units, potentially enabling the retirement of older power plants.

Some of the applications are already under early commercial development; several merchant energy storage developers are piloting fast energy storage technologies for use in system regulation. In addition, some wind developers that experience curtailment due to insufficient transmission capacities are investigating energy storage solutions.

At a much larger scale, the Dutch government is exploring the creation of an “energy island,” whereby a hollowed-out artificial island in the North Sea would use pumped hydroelectric in reverse—windmills would pump water out of the island, and then hydroelectric turbines could generate electricity when it is desired from water flowing back into the island’s cavity.[10]

2.3 Transmission and Distribution Applications

Transmission and distribution (T&D) applications are not as advanced in development and deployment as generation energy storage applications. In addition, regulated utilities in general must be the first to embrace energy storage as a cost-effective option, and traditionally the T&D sector relies on proven technologies with asset lives of 40 years or more,

[10] “The Energy Island Stores Electricity,” *European Energy Review*, December 2007.

Table 2-1: Energy Storage Technology Generation Applications

Application	Definition	Nature of Benefit	Benefit Magnitude	Power Requirements (Max)	Duration Requirements	Other Requirements	Structural Issues	Comments
Governor response	Generator autonomous dynamic response to frequency	Renewable sources typically lack governor response, which is essential for system stability. Increasing conventional unit governor response for renewable sources will cost the markets	Compensate for lack of renewable sources governor response	1–5% of associated generation	Seconds to a few minutes	Sub-second response	None; standards for renewable governor response are lacking	This is an unexplored area meriting R&D to determine value in integrating renewable sources
Regulation	Second by second adjustment of power production to match load and schedules and regulate system frequency	Regulation is a defined ancillary service with annual costs to markets on the order of millions of dollars. Storage can displace conventional fossil generation for this purpose and free up generation capacity for energy production. Renewable generation typically lacks regulation capability	0.2–0.5% system wholesale energy costs	Typically 1–2% of system peak overall	Studies show that 15–30 minutes duration is required to be effective	Rapid (<10 sec) response	In many markets regulation often overlaps short-term balancing energy. Control algorithms can be adjusted to exploit fast storage response and use storage first for regulation	Ancillary markets are already a target of merchant storage. Charging losses must be paid in balancing markets so efficiency is a key
Balancing energy/ Real-time dispatch	Adjustment of production economically/market based on a minute-by-minute basis to match demand	In some markets hourly schedule changes cause "spikes" in balancing requirements and prices. Storage used for this purpose would mitigate the spikes. Renewable volatility is expected to greatly increase balancing energy needs, which would increase prices and reduce capacity available for base/scheduled energy production; storage can mitigate this problem	2– 3% of today's wholesale costs; benefit is to reduce costs and potentially avoid increases to renewable penetration growth	Balancing is typically 2–3% of system energy today and may double with large renewable penetration	1 hour or more	Charge efficiencies must be settled in the real-time markets so efficiency becomes an important attribute	None; standards for renewable governor response are lacking	Another target of merchant storage; short-term price arbitraging

Application	Definition	Nature of Benefit	Benefit Magnitude	Power Requirements (Max)	Duration Requirements	Other Requirements	Structural Issues	Comments
Reserve augmentation	Conventional generation provides spinning and operating reserve as back-up against the failure of resources	Storage can provide short-term reserves and enable slower generation to participate, freeing up additional capacity from economic units online	Conventional generators charge an "opportunity cost" when providing reserves – this cost can be avoided	Spinning reserve is typically matched to the largest unit in a control area or congestion zone; typically 1000–1500 MW	15–30 minutes if backed up by slower generation	Storage must be kept in a state of charge in order to supply reserves	Unexplored territory except for hydroelectric resources	Merits R&D
Intra-day production shifting	Some renewable energy resources have intra-day behavior (e.g., mountain wind locations) which impose scheduling and load matching challenges	Storing renewable production for several hours will utilize more renewable energy and reduce peak fossil production	Depending upon the amount and daily variability of renewable sources this can be a very large economic benefit	Depends upon specific resources. Could be a range of 30–50% of resource maximum power capacity	Hours	Energy capacity has to be economic against the value of energy captured	Eligibility for Investment Tax Credits should be considered	Some wind farm developers are exploring this application
Diurnal renewable levelizing	Diurnal renewable levelizing	Storing renewable energy resources from daily peak production for use at peak load hours	Depending upon the amount and daily variability of renewable sources this can be a very large economic benefit	Can be as much as 50% of renewable resource production	6–12 hours	Energy capacity has to be economic against the value of energy captured	None	Economics are uncertain with today's technology
Weekly production levelizing	Weekly production levelizing	Store production on weekends for weekday use	Pumped hydro is the vehicle for this today and provides large benefits	Can be 20–30% of peak load for two days	48 hours	Needs large energy storage capacities; only pumped hydro proven for this today	None	Typical pumped hydroelectric application
Seasonal production levelizing	Seasonal production levelizing	Store seasonal resources for use in peak load seasons	Hydroelectric facilities provide this	Typical only of large hydro reservoirs today	Months		None	Typical hydroelectric function

Source: Table created for *Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid* by EAC Energy Storage Technologies Subcommittee 2008.

which is difficult to demonstrate for many emerging technologies.

Transmission capacity to bring remote generation to load centers is currently limited, although new transmission infrastructure is being planned and built in many areas. Increasingly, new generation has to be sited far from population centers, which can place additional strain on the grid. Wind power generation in particular is often located in remote or rural locations, which requires the installation of new transmission. Because wind resources typically have capacity factors below 50%, it is often the case that associated new transmission rated at the full power capacity of the renewable resource is not economical. For some wind power projects, it may be cost-effective to either build transmission capacity for slightly less than the full nameplate capacity of the project and simply curtail output during the small number of hours per year when output exceeds the available transmission capacity or to add energy storage to enable the dispatch of the energy at a different time.

One noteworthy leader in applying energy storage to T&D applications is American Electric Power (AEP). AEP is deploying a 5.0 megawatt (MW) sodium sulfur (NaS) battery to solve a transmission issue in southern Texas. AEP has stated a commitment to add 1,000 MW of energy storage to their grid by 2020.[11]

Energy storage technologies may provide a way to capture power production that would otherwise be curtailed and reserve it for a time when the transmission grid is not loaded to capacity. Energy storage also affords the transmission owner/grid operator a chance to defer transmission expansion for a period; transmission capacity is generally not incrementally increased. This ability to defer transmission expansion is an example of energy storage providing mutual benefits to generation and transmission. However, the costs of energy storage options need to be compared to other options, including the construction of new transmission infrastructure, that benefit all generators as well as consumers via enhanced reliability and lower overall costs.

It is a matter of debate whether the cost of energy storage technologies utilized to shift transmission utilization to match capacity should be a generation or a transmission asset because of its multifaceted implications for business models, sources of financing, and regulatory cost recovery. Energy storage is described here as a transmission application because it is directly linked to the transmission system and its operation, without any bias towards its classification as such for regulatory or business model questions. However, it is worth noting that energy storage used for this purpose can also be used for energy price arbitraging and production levelization, which are normally generation functions and which developers prefer to perform on a merchant basis so that they can access market prices.

Transmission congestion is already a peak period issue in many parts of the country. Congestion uplift charges are typically considered as part of fuel cost adjustments by most regulated load-serving entities and can be tens to hundreds of millions of dollars each month. The impact of congestion is to force the use of expensive generation resources (combustion turbines or older steam units converted to oil and gas) closer to the load center instead of less expensive coal and hydroelectric (or increasingly, wind power) resources, which can be used in remote locations. Therefore, large-scale energy storage is another way to mitigate transmission congestion, if the economics are viable.

A special case of congestion relief occurs when the limiting transfer capacities are not the physical capacities of the transmission paths in question, but rather are reliability limits arising from post-contingency loading or stability conditions. In the western United States, system dynamic and transient stability limits impose restrictions on the north-south power flows, below the physical limits of the transmission lines. In the Northeast, post-contingency voltage conditions similarly limit transfers below the physical capacities.

Very fast energy storage has the potential, as yet unexplored or validated, to relieve many of these reliability limitations. In the event of a contingency (a sudden unplanned outage of a line or generator), the inverter-based storage could theoretically respond in a period of power system cycles (<0.16 sec) and provide a stability or voltage augmentation. The economic value of relieving these reliability limits is considerable, making this potential role one that should be studied. Allowing the transmission circuits to be loaded to full thermal limits could result in

[11] American Electric Power, "AEP to deploy additional large-scale batteries on distribution grid," news release, September 11, 2007.

increased power transfers for better economics and would be important as new generation sources are located far from load centers. This improvement could be a bridge until expanded transmission capacity is permitted and constructed and would similarly provide capacity factor benefits to some new transmission facilities.

At the distribution level, energy storage can provide benefits similar to those it provides at the generation and transmission levels: providing local peak power/time shifting capabilities, grid reinforcement against peak and against reliability incidents, and specialized power electronics-based benefits. Providing these benefits with fossil fuel-based generation is usually problematic because of siting and environmental issues, and distribution applications require completely unmanned operation. Appropriate energy storage technologies do not suffer from these drawbacks. As an example, while pumped hydroelectric facilities can only be located where suitable dam sites can be created (which is hardly an urban option), and compressed air energy storage (CAES) may be difficult to site in volume in any suburban/urban area, other technologies, particularly dry batteries, lend themselves to distributed deployment in basements and garages. Table 2-2 shows the potential applications of energy storage in the transmission and distribution systems.

While the deployment of energy storage technologies on distribution systems can offer all of the benefits available from larger storage units at transmission and generation levels, it can also offer some additional value. The flattening of demand on station transformers and circuits enables the deferral of

Table 2-2: Transmission & Distribution Energy Storage Applications[12]

Application	Benefit	Quantification	Power Requirements	Duration Requirements	Issues	Comments
Transmission capacity factor for renewable sources	Capture renewable production and deliver when transmission capacity is available	20–50% of renewable capacity	20–30% of renewable peak production	6–12 hours	Uncertain long-term economics as capacity is built	Economic issue for wind developers today
Transmission congestion relief	Generalized application of above	Potentially large in localized applications	Equal to typical congested power on path	Hours	Uncertain long-term economics as capacity is built	Likely to grow in importance
Transmission reliability limit relaxation	Specialized technical version of congestion relief relying on very fast storage	$10 million to more than $100 million	0 MW to 1000 MW	Seconds to 15 minutes	Unexplored and will need rigorous analysis and demonstration	Would be backed up by quick start reserve in some cases
Transmission capital deferral	Relieve short-term congestion	1–several years carrying costs		Hours	Very site specific	Similar to congestion relief
Substation peak load/Backup	Defer transformer upgrades (and other upgrades) due to peak load growth	$M per station for 2–5 years deferral	2–10 MW	Hours	Economics unanalyzed	Links to loading issues around distributed generation penetration also
Voltage support	Storage can provide local real power at high power factor	Economics need analysis	Varies with application	Varies with application	Cost compared with alternative solutions	This application is being piloted by at least one utility
Reliability enhancement	Provide down-circuit supply while outages are restored	Outage costs vary greatly depending with duration and consumer	2–10 MW	Hours	Economics unanalyzed	Alternative to switching on long rural circuits

Source: Institute of Electrical and Electronics Engineers (IEEE) 2008.

[12] "Source: Institute of Electrical and Electronics Engineers (IEEE), 2008.": Nourai, A., V.I. Kogan and C.M. Schafer, "Load Leveling Reduces T&D Line Losses," IEEE Transactions on Power Delivery, no. 23 (Institute of Electrical and Electronics Engineers, October 2008), TPWRD-00819-2007: 2168 – 2173.

distribution upgrade capital. In addition, the availability of the stored backup power closer to the end-use consumer at the distribution level would offer inherently higher service reliability than what could be offered with energy storage at transmission or generation levels. Due to the nonlinear nature of T&D losses, diurnal peak shaving of energy storage devices would actually reduce T&D losses. The closer the energy storage is located to load, the greater the reduction in T&D losses, particularly given that a high percentage of the T&D losses are on the distribution circuits. Another additional value of distribution-level energy storage, compared to larger units deployed at transmission and generation levels, is the inherent increased security and reliability in storing energy in multiple locations instead of concentrating them in fewer large centers. A unique distribution system has significant value and should be considered in locating energy storage devices.

2.4 END-USER APPLICATIONS

Energy storage can be used as an asset for commercial and industrial end-users. For these applications, the device may be utilized as a standalone asset or in combination with distributed generation (DG).

For residential end-users, energy storage can add value as a backup power device, providing power during outages for vital appliances. In addition, it can play a role with renewable energy, such as rooftop solar power, as a way to store excess renewable energy production for use when the renewable energy resource is unavailable (i.e., when the sun is not shining or the wind is not blowing), allowing the consumer to avoid using grid energy at those times. Of course, grid electricity (where available) may be a more cost-effective option for maintaining power during these periods.

For commercial end-users, energy storage technologies can fill a unique niche in providing backup power for short-term interruptions. Typically, a facility will use DG technologies to supply backup power. However, many interruptions are often short in duration and happen before a generation device can "ramp up." In combination with DG, energy storage can provide ride-through protection for short-term interruptions and serve as a bridge to a facility generator in case of long-term outage.

This short-term storage market is the very mature uninterruptible power supply (UPS) market arena that is currently booming. According to research conducted by the Uptime Institute, total sales this year in the United States will be over $1.4 billion and growing.

UPS devices have been used by commercial end-users with specialized reliability requirements (high-value process/production industries). With environmentally and economically attractive energy storage, possibly assisted economically by price arbitraging and linkages to demand response / load management, this application may become increasingly relevant for other commercial end-users.

Energy storage can be considered simply another "generation option" for an end-user. Today's user may be able to use all power sources—the grid, energy storage, and DG—in combination to optimize usage and costs for power, and as a result, maximize economics and profits. If, in the future, the utility decouples rates and implements a demand or capacity charge, the user may be able to pay a lower demand charge if they are willing to accept curtailed service for essentials only—when the renewable production is absent and the energy storage is exhausted. Energy storage technology can serve individual residences or even a microgrid serving a number of commercial users.

It is also conceivable that energy storage technologies, interconnected with end-user controlled demand-side resources and DG, will be used to shift grid demand to low-priced periods and avoid peak real-time prices. Again, this is also a viable application for commercial as well as residential users. It is anticipated that significant PHEV penetration will lead to such applications, as consumers realize the desirability of charging their vehicles at off-peak prices.

There is also the possibility for the linkage of end-user energy storage with utility operations to achieve some of the same benefits as described in the T&D application section. Because of the costs of control interconnection and the need for some assurance that the energy storage technology will perform when needed, this system is likely to first appear in high-value/high-density locations, such as downtown urban underground networks. The particular operational problems of underground networks and the high costs of capital expansion and energy in these areas make inter-controlled end-user DG and energy storage an interesting opportunity for the T&D utility. This opportunity implies that end-user energy storage is capable of discharging back to the grid via a net metering scheme under utility control.

A very specialized end-user application, under investigation in Europe and by the New York State Energy Research and Development Authority (NYSERDA), is the use of energy storage technologies to levelize the peak power demands of electric rail operations and to reduce rail power distribution losses; trains consume as much as 75% of their power when they are accelerating out of a station. Energy storage deployed at stations would reduce the losses in delivering power to the train (catenary losses are quite high—more than double typical T&D losses due to the need to use steel for the catenary conductor) and would allow for the capture of regenerative braking as well.[13] Using energy storage avoids the expensive or impractical retrofitting of trains, which would be necessary for the use of flywheels for similar purposes.

One of the most appealing benefits of deploying a Smart Grid is that the “smart” technologies can be used to shift or control demand to reduce peaks. Some demand response / load management programs require altering consumer behavior, although other demand response / load management programs can operate automatically and without the consumer being aware of its deployment. A virtue of energy storage technology is that it can accomplish the same supply/demand balancing without imposing behavioral constraints on consumers. On the other hand, the benefit of demand response / load management measures is that they are typically lower in cost.

Demand response / load management is increasingly a market resource, incorporating the provision of ancillary services such as reserves and real-time energy, as well as some demand response / load management aggregators that aim to provide system regulation. Utility-scale energy storage coupled with demand response / load management provides the aggregator a higher responsiveness and certainty of response, making demand response / load management participation in ancillary services markets more attractive.

As with distributed generation, energy storage at the end-user site is a natural complement to demand response / load management applications and has the chance to play a vital role in demand response / load management programs. Ultimately, end-users may use their storage in net metering situations, as some renewable energy resources are used today, to sell power back to the grid at peak times. Whether energy storage economics will make this option viable is not yet known.

Other niche applications for energy storage technologies include cranes, container ports, and other applications characterized by short bursts of peaking power in which managing local demand and/or losses is of value.

These niche applications are mentioned only to illustrate that many other high-value, end-user applications will come forth once the energy storage technology is proven effective. Table 2-3 shows the end-user applications and value propositions that could be derived from energy storage.

[13] New York State Energy Research and Development Authority, Program Opportunity Notice 1217, July 2008.

Table 2-3: End-User Energy Storage Applications

Application	Benefit	Quantification	Power Requirement	Duration	Comments
Storing renewable distributed generation (DG) production	Capture renewable DG production for use when wanted and reduce grid consumption; mitigate capacity charges as well	Benefit up to value of renewable energy at peak hour's pricing	Equal to local DG peak production	Hours	Has been promoted in conjunction with distributed Photovoltaic generation as a way to store solar derived energy for overnight charging of PHEV
Time shifting of demand to avoid peak prices	Avoid high real-time prices at peak	$100/MWh or more	Equal or less than peak load	Hours	Has not been explored
Price arbitraging in real-time pricing situation	Same as for storage in generation balancing energy	May mitigate high ramping balancing costs	As desired	30 minutes	Not allowed under existing tariffs
Reliability enhancement	Avoid interruptions	Linked to value of production and cost of interruption	Equal to peak load protected	Minutes to hours	Linked to demand response / load management and backup generation
Utility reliability enhancement	Allow utility control for targeted enhancement	Linked to utility capital deferral	Equal to peak load typically	Minutes to hours	Unexplored but potentially attractive in urban situations
Plug-in hybrid electric vehicle Integration	Lower cost of charging by only using off-peak power	Lower cost of driving plus utility capital deferral	Equal to vehicle power draw	Hours	Has been promoted for diurnal application or for peak levelizing against fast charging demands
Demand response / load management integration	Make demand response / load management participation in markets more attractive	Not quantified as of yet	Similar to demand response / load management that is replaced	Minutes to hours	Commercially being investigated today
Renewable demand response / load management	Renewable volatility and difficulty of control make them unreliable for demand response / load management applications. Storage can be an enabler	Not quantified as of yet	Similar to demand response / load management that is replaced	Minutes to hours	Has been considered by at least one demand aggregator as a tool to moderate demand response / load management impacts on affected end users
Railroad acceleration support	Avoid significant variable (I2R) losses	Catenary losses are 15–20%	10 MW per station	Minutes to hours	Being investigated today

Source: Table created for *Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid* by EAC Energy Storage Technology Subcommittee 2008.

Chapter 3
Regulatory Issues and Potential Barriers to Deploying Energy Storage Technologies

3.1 Regulatory Uncertainty

Energy storage technologies face regulatory barriers to their implementation in the electric power industry. Like any new or emerging technology, energy storage has a lack of regulatory history to guide regulators on its use. In addition, there is no overall strategy or policy on how energy storage technologies can be incorporated into existing components of the electric power industry. In fact, there are very few regulations that explicitly address energy storage. The lack of any specific regulations leaves utilities uncertain regarding how investment in energy storage technologies will be treated, how costs will be recovered, or whether energy storage technologies will be allowed in a particular regulatory environment. The primary reason for the lack of regulation is that energy storage on a utility-scale basis is very uncommon and, except for pumped hydroelectric storage, is relegated to pilot projects or one-time deployments. Utilities have not used energy storage to address capacity issues and are perhaps not accustomed to considering the use of a nontraditional technology, such as energy storage, to address issues in ways different from those used in the past.

An additional reason for the uncertainty regarding the treatment of energy storage technology stems from whether energy storage technology is seen as being related to generation or transmission. The problem, from a regulatory perspective, is that energy storage applications can provide functions related to both, as discussed in Chapter 2. The bulk storage of electricity, for example, if used by a utility to shift the generation of electricity from a time of low-cost generation, such as in the middle of the night, to a time of high-cost generation, such as during peak use, would be seen as similar to generation. On the other hand, in addition to reducing or eliminating the need for peaking facilities, this type of action could also reduce transmission congestion, provide voltage support at a time of peak use, and provide other ancillary services that support transmission functions. The ability of energy storage technology to fill multiple roles in both transmission and generation leads to confusion and uncertainty about how energy storage should be regulated.

3.2 Utility Reluctance

The multiple applications of energy storage spread out the transmission and generation benefits that energy storage provides as well as the income streams provided by these benefits. Regulated investor-owned utilities generally need to be assured of cost recovery before proceeding with major investments, and a new technology such as storage may present challenges in obtaining regulatory approval. Such reluctance results in a barrier to deploying widespread energy storage technology due to the indeterminate state of the technology and the costs of implementation. This confusion affects the cost recovery status of energy storage projects because these utilities are uncertain that a basis can be made for the cost recovery of this new, innovative technology. If an energy storage project is compared directly to a peaking generation facility or to developing a new transmission line, without taking into account the system benefits of energy storage, the cost of the energy storage project may not seem justified if the problem can be addressed through a less-expensive solution. However, it may be difficult to quantify or compare the costs and benefits of all of the different functions provided by an energy storage project to those of a single generation or transmission project.

Because multiple benefits can be provided by energy storage applications, the potential income streams from energy storage are also diverse. For example, an energy storage project may provide the benefits of improved reliability and deferral of transmission improvements. An owner of storage may also attempt to arbitrage the price of electricity by storing when the price of electricity is low and selling back to the grid at peak demand when the price is higher or by providing other ancillary services. However, these benefits would not provide sufficient income if they were considered individually, but combining multiple income streams would allow for full cost recovery of the energy storage project.

However, because these benefits address different functions (generation vs. transmission), it may be difficult to measure the different benefits and allow for full cost recovery based on these benefits. Energy storage provides benefits that can transcend narrowly focused applications categories; for example, energy storage that increases the effective capacity factor of a renewable energy resource improves the economics of that resource and also reduces overall emissions. In addition, the deployment of energy storage technology may allow deferral of transmission expansion (or more realistically, allow higher-priority transmission expansion to take precedence). Application of energy storage avoids a need to carry higher-spinning or short-term generation reserves on a renewable energy project and frees up generation capacity, thus allowing deferral of traditional generation expansion. The challenge for public policymakers is to design incentive structures that fully recognize all of the potential benefits without creating an incentive-driven competition between energy storage and other desirable investments.

Generators, or residential consumers with small-scale renewable energy generation, may deploy energy storage technology for arbitrage purposes; however, the revenue from arbitrage may not be sufficient to cover the costs of an energy storage project and may present another potential barrier to adding more energy storage to the electric power delivery system infrastructure.

A utility that is guaranteed to receive cost recovery of either a transmission or generation project, or both, may have little incentive to put an energy storage project in place. Rather than invest in energy storage technology, a utility may simply opt to construct a transmission and/or generation facility, the costs of which are more likely to be approved and recovered. In addition, state utility regulators may be reluctant to allow cost recovery for an innovative energy storage technology. State utility regulators may instruct the utility to rely on proven technology to address issues that could be solved through energy storage technology.

3.3 Electricity Pricing and Energy Storage Technologies

The current typical pricing structure of flat rates does not provide consumers with any incentive to invest in energy storage applications. Consumers that are exposed to time-of-use or real-time prices will have an incentive to invest in storage if the price differentials are significant, but today relatively few residential or small commercial customers are under such pricing schemes. However, energy storage applications for larger consumers may provide other benefits, such as reducing or eliminating demand charges. Energy storage for all consumers could also be used for demand-side resource programs, if there is an incentive associated with this benefit for the consumer.

To successfully overcome regulatory obstacles to deploying energy storage technologies, a definition of such technologies must be adopted by regulators as a class of assets within the generation, transmission, distribution, or distributed/end-user sectors according to their ownership and application. Furthermore, regulators must then provide appropriate regulations on the use of energy storage in each case. Incentives or allowances for cost recovery should be made by either allowing the energy storage technology owner to obtain multiple income streams to offset the costs or allowing cost recovery through rates. By explicitly addressing the issue of implementation of energy storage technology and indicating that the technology is a cost-effective option that is available to address market issues, the largest barrier to successful development and deployment of energy storage technologies will be overcome.

Chapter 4
Potential for Energy Storage in Plug-in Hybrid Electric Vehicles

Plug-in Hybrid Electric Vehicles (PHEVs) are one of a cluster of technologies that can provide a way to reduce carbon emissions (CO_2), as well as pollutants such as nitrogen oxides (NO_x), sulfur oxides (SO_x), and mercury. PHEVs will also contribute to increasing energy security by reducing the nation's dependence on foreign oil as a strategic commodity. Finally, PHEVs will combat the rising costs of transportation.

This chapter discusses the potential impact of a significant penetration of PHEVs both in terms of increased demand on the electric power delivery system and the possible benefits of the distributed energy storage this technology can offer. As described in Chapter 2, using a PHEV to provide energy storage is called vehicle-to-grid (V2G) power, and it leads to what some call the "cashback hybrid" approach. This approach is further discussed in this chapter.

It is likely that PHEVs that have an all-electric range of approximately 40 miles will penetrate the United States market in significant numbers in the near future. While the exact timetable is uncertain, many analysts expect that the trend will begin in 2010 and be in full swing by 2050. One study predicts a deployment of 30% of new light-duty vehicle sales by 2030. [14] The study suggests that "plug-in hybrid vehicles, building upon the engineering and market acceptance of traditional hybrids, are expected to enter the U.S. market around 2010 and to gain market penetration through 2050 because of their superior fuel performance and environmental benefits."[15]

Another study concludes that with "proper changes in the operational paradigm, [the U.S. electric system] could generate and deliver the necessary energy to fuel the majority of the U.S. light-duty vehicle fleet."[16] The study does not address any additional benefits or costs of V2G electric power generation or spinning reserve services that PHEVs may provide in the future.

PHEVs will rely principally on the electric power grid for their fuel. At present, there are dozens of new hybrid vehicles planned for 2010 by various manufacturers around the world. It is estimated that by 2016, there will be two million hybrid vehicles on the road in the United States.

[14] EPRI Energy Technology Assessment Center, *The Power to Reduce CO2 Emissions: The Full Portfolio,* Prepared for the EPRI 2007 Summer Seminar, August 2007: 14.
[15] Ibid.
[16] Michael Kintner-Meyer and others, *Impacts Assessment Of Plug-In Hybrid Vehicles On Electric Utilities And Regional U.S. Power Grids Part 1: Technical Analysis* (Pacific Northwest National Laboratory, 2007): 1.

A hybrid electric vehicle (HEV), such as the Toyota Prius, has both an electric motor and a combustion engine. The battery pack is small (about 1 kilowatt hour [kWh]) because the electric drive is used only for assisting acceleration and generally managing the alternations that occur between electric and engine power. This system provides good overall performance using a smaller combustion engine. This configuration improves fuel economy by 20–35%, allows for optimized operation of the engine, can capture braking energy and store it in the battery, and can reduce engine emissions due to improved engine control. The batteries sustain their charge during the driving cycle and are not normally designed to be capable of accepting a charge from the grid. The HEV, like conventional automobiles with only combustion engines, has a range limited only by the size of the fuel tank.

Today, the average commuter drives less than 40 miles per day. A PHEV is an HEV with a much larger battery pack (5–10 kWh) and the ability to operate for 20–40 miles in an electric-only mode. The combustion engines are smaller and can be optimized by functioning as a generator that charges the batteries using onboard fuel. PHEVs store enough electricity, presumably from an overnight charge, to permit the first 40 or so miles to be driven solely on electric power. Beyond this range, PHEVs function like HEVs—they are intended to be charged from the grid, and the small combustion engine would only be used when the automobile's battery is substantially depleted of charge.

In addition, as mentioned in the introduction of this report, some utilities are implementing a Smart Grid that will contain a high level of smart technologies—technologies with embedded computers that collectively can provide a network of distributed intelligence. The Smart Grid will incorporate standardized communication protocols, affording significant interoperability with other devices. It will be integrated with a smart electricity infrastructure at the distribution level, with the energy management system (EMS) at the transmission level, and with grid operations and planning. Some predict this vision will be implemented by 2025. One study suggests that "with parallel advances in smart vehicles and the smart grid, PHEVs will become an integral part of the distribution system itself within 20 years, providing storage, emergency supply, and grid stability."[17] The confluence of advances in batteries and grid intelligence may provide the potential to transform the transportation sector over the next 20 years.

4.1 Current Status

Support for energy storage technology applications is growing. Recent projects implemented by the Institute of Electrical and Electronics Engineers (IEEE) and the American Institute of Chemical Engineers focused on PHEVs and "massive electricity storage" in the electric power grid, respectively.[18]

In July 2008, General Motors (GM) announced that it is collaborating with utilities and the Electric Power Research Institute (EPRI) to prepare the nation's electric power delivery system infrastructure for the widespread sale of PHEVs, such as the Chevrolet Volt, which will likely use a 1.4 L, non-turbo, 4-cylinder engine. This is a landmark, first-of-its-kind effort through which GM will work directly with utility companies and EPRI to ensure that codes, standards, and grid capabilities are in place so that the infrastructure will be able to support the Volt when it comes to market.[19] This collaboration involves 34 utility companies spanning 37 states and 3 Canadian provinces. Most of the major utility companies are included and represent a very large volume of the U.S. population. Even so, neither EPRI nor GM can unilaterally speak for their respective industries and supply chains, making it important going forward to ensure that developing a successful PHEV is open and responsive to a broad range of industry participants from both sectors.

4.2 A Three-Phase Approach for Future Development

At present, most experts agree that the adoption of PHEVs will begin in the short term with vehicle charging managed by pricing that encourages charging in off-peak times. This grid-to-vehicle concept gives cost benefits to those agreeing to

[17] Revis James, "The Full Portfolio," *Electric Perspectives*, Jan/Feb 2008, http://mydocs.epri.com/docs/CorporateDocuments/AssessmentBriefs/The_Full_Portfolio.pdf.

[18] Bernard Lee and David Gushee, *Massive Electricity Storage: AICHE White Paper* (New York: American Institute of Chemical Engineers, June 2008), http://www.aiche.org/uploadedFiles/About/DepartmentUploads/PDFs/MES%20White%20Paper%20submittal%20to%20GRC%206-2008.pdf.

[19] Chuck Squatriglia, "GM Joins Utilities to Ensure Plug-In Hybrids Can Plug In," Wired.com, July 21, 2008, http://blog.wired.com/cars/2008/07/gm-joins-utilit.html.

charge their vehicles at night, thus filling in the load valley, and penalizes those charging during the day. However, there are only about 54 million garages for the 247 million registered passenger vehicles in the United States today. Because most consumers without garages do not have a way to charge a plug-in vehicle, there is a substantial amount of infrastructure that will have to be built. Fortunately, that work has already begun with companies such as Coulomb Technologies, which offers products and services that provide a smart-charging infrastructure for plug-in vehicles.[20] Long-term, successful management of vehicle charging will require significant deployment of Smart Grid technologies, which will take time to design and implement.

Phase One

Today, the prospects for any PHEV charging are limited to vehicle owners who can provide a nightly parking location with access to a power outlet. As noted above, this need is a challenge for the vast number of owners who rely on street parking or parking facilities for nighttime parking. The distribution of early PHEV sales may skew only to owners who have garages, and the lack of a convenient charging location may also influence buying decisions. However, the long-term availability of charging locations is a critical infrastructure need, if PHEVs and HEVs are to become the dominant vehicle type in the United States. Even when owners have garages, it is not uncommon for automobiles to be parked in driveways—whether because the household owns more automobiles than they have garage space or because the garage is used for storage, as a workshop, or for some other purpose.

Owning a PHEV and recharging it every night for a minimum charge would increase the average U.S. consumer's electric consumption by approximately 50%. For a 40-mile range PHEV, the maximum consumption would be about 14 kWh. An average household with a monthly consumption of 850 kWh would increase its demand by no more than approximately 420 kWh. According to a Pacific Northwest National Laboratory 2007 report, "providing 73% of the daily energy requirements of the U.S. light-duty vehicle fleet with electricity would add approximately 910 billion kWh"[21] to the current load. While this is an energy load, it is also a potential source of energy storage. If it is assumed that there is a uniform distribution of battery charge, that automobiles are driven on average two hours per day, and that the automobiles are available for use by a utility when they are not being driven, the average energy storage available for discharge or charge would be 417 billion kWh. This capability is valuable to the electric power grid for peak shaving, valley filling, and reserve spinning for guarding against losses due to contingencies.

A major challenge to consider is how PHEV usage will interact with high levels of renewable energy generation capacity, especially wind and solar power. Some types of renewable energy generation have strong diurnal characteristics, which are obvious with sunlight limitations for solar power and which vary somewhat according to geography for wind power. If the PHEV charging load matches peak renewable energy production, then the electric power industry will be provided with an ideal situation. If the PHEV charging does not match daily renewable energy generation cycles well, then the mismatch is problematic, and deployment of energy storage technology has an even more important role in supporting the attainment of high renewable portfolio standards.

Uncertain Future

The most influential factors affecting the PHEV industry between now and 2030 are uncertain regulatory requirements, including consumption regulations, carbon taxes, and emissions standards. Technology breakthroughs, primarily in batteries, manufacturing technology advancements and deployment, incentives for early adopters, and the development of industry standards for components and technologies are also important uncertainties. Infrastructure design and associated costs are significant issues, but they are currently being addressed by several entities in anticipation of the successful adoption of PHEV technology. The next generation of vehicle purchasers is expected to be more conscious of "green" benefits and be aware of the negative effects of emissions. Nevertheless, the United States appears to be on a path to the adoption of a significant number of PHEVs, and the electric power grid will have a central role in assuring their adoption.

[20] CNET, Green Tech, "Coulomb unveils electric-car charging stations," July 22, 2008, http://news.cnet.com/8301-11128_3-9996353-54.html.

[21] Michael Kintner-Meyer and others, *Impacts Assessment Of Plug-In Hybrid Vehicles On Electric Utilities And Regional U.S. Power Grids Part 1: Technical Analysis* (Pacific Northwest National Laboratory, 2007).

Phase Two

The next logical stage of infrastructure development is the vehicle-to-home (V2H) and/or the vehicle-to-building (V2B) concept. Here, a PHEV would have the ability to communicate with the home or small businesses. The PHEV battery might be operated in a way that makes it available for emergency backup for the home or business in addition to allowing the home to manage its charge/discharge schedule. Optimization of onsite renewable energy sources would be a strong benefit because the consumer could take advantage of the additional production of the on-site energy, such as wind power at night, when there is minimal demand from the home or business. This system would be the first instance of bidirectional flow with smart charging.

Phase Three

In the long term, the envisioned V2G concept allows for full bidirectional controlled flow between the vehicle and the grid. Control of the bidirectional electric flow could include payments to owners for use of their automobile batteries for load leveling or regulation and for spinning reserve (the cashback hybrid incentive). Kempert and Wellinghoff say that, "it is our opinion that the potential benefits of vehicle-to-grid PHEVs are so compelling that the technology is clearly an enabler of both the Smart Grid and the successful market penetration of the PHEV itself."[22] An article in the magazine *Public Utilities Fortnightly* argued that the payments to individual PHEV owners using V2G technology could be as much as $2,000 to $4,000 per year per vehicle for just spinning reserve or regulation services.[23] Because the flow of energy is bidirectional, electric service providers can benefit in addition to PHEV owners by controlling or at least monitoring the flow between PHEVs and the grid. Possible benefits to utilities include the ancillary services mentioned earlier, demand response / load management assistance from PHEVs, and green power credits.

[22] Jon Wellinghoff and Willett Kempton, March 2007 comments on *DOE Plug-In Hybrid Electric Vehicle R&D Plan, External Draft,* http://www.ferc.gov/about/com-mem/wellinghoff/3-30-07-wellinghoff.pdf.

[23] S. Letendre , P. Denholm, and P. Lilienthal, "Electric & Hybrid Cars: New Load or New Resource?" *Public Utilities Fortnightly*, December 2006, 28–37.

Next Steps

In order to support this model, considerable work must be undertaken to develop the market protocols, information exchange standards, and possibly the electronic interfaces that will govern V2G integration and interaction. PHEVs will bring together the entire value chains of the automotive/transport sectors and the electric supply sectors—which currently do not share common standards or standards bodies.

To implement this concept, third-party ownership of batteries may be needed. The third-party entity would be a party other than the PHEV owner or the automobile manufacturer and may include an electric service provider, a generic profit center, an information technology company such as Google, or an emissions credit-trading organization. Consumer benefits may include a free or reduced-price battery accompanied with warranty service to ensure performance, reliability, and safety. In addition, automotive original equipment manufacturer (OEM) or third-party ownership would likely enhance the prospects of environmentally secure end-of-life disposal of the batteries, an issue of high environmental importance. Furthermore, there is a possibility that after batteries have reached the end of their useful life for vehicular purposes (after degradation of charge capacity has reduced vehicle range), they may still have economic use in power backup or utility applications when suitably repackaged. This repackaging prospect, coupled with the possibility of a vehicle retrofit with a future higher-performance battery is very real. However, the first-generation PHEV vehicles will not include V2G capability primarily due to warranty concerns about the batteries and a desire to avoid additional complexity and cost.

4.3 Regulatory and Institutional Policy Issues

PHEVs, as distributed energy storage solutions for V2G applications, face the same issues as other energy storage projects. The lack of regulatory clarity on how energy storage is defined and regulated as well as how cost recovery issues will be resolved are potential barriers to investment, as discussed in Chapter 3. The extent to which PHEV owners can participate in V2G applications (such as providing load smoothing and ancillary services) and receive compensation for participating in these programs is still unclear.

Phase one, as described above, in which PHEV owners are encouraged to charge their vehicles at night, would require changes in pricing and/or metering policy to ensure that consumers fulfill their responsibilities. Policymakers could provide incentives to PHEV owners through time-of-day pricing, with higher rates at times of peak use and lower rates at night, to encourage PHEV "off-peak" charging. In phases two and three, additional regulatory approval would be required for meters or other communication technologies that can regulate the charging or discharging of PHEV batteries to occur at specific times. Charging would occur, as described above, at night or other times of low load, while discharging would occur at times of peak load or when necessary to provide other ancillary services. Regulatory approval would be most likely required to ensure that these strategies are properly implemented and that PHEVs are incorporated into a broader plan for overall grid transformation, the development of DG, or the implementation of Smart Grid technologies.

PHEVs and electric vehicles (EVs) were awarded incentives up to $7,500 per vehicle in the Emergency Economic Stabilization Act of 2008 passed by Congress on October 3, 2008.[24] This incentive is intended to make the price of a PHEV competitive with other similar-class vehicles for early adopters. In addition, the development of these vehicles will likely benefit from direct tax incentives to suppliers or purchasers as well as locally specific indirect incentives, such as high-occupancy vehicle lane access, parking access, and incremental cost rebates. There is already concern from policymakers about how to replace declining gasoline tax revenues that are a crucial element in the support of highway infrastructure. In the event that PHEV adoption succeeds wildly, two important concerns will include how to fund utility infrastructure to support PHEVs and how to replace the gasoline tax revenues to fund highway infrastructure. Utility infrastructure modernization costs could be socialized through general T&D tariff increases, funded incrementally through a mechanism tied to local PHEV sales, or funded through some other mechanism. Funding grid modernization is an important question that emphasizes the importance of understanding the specific local and regional infrastructure needed to support different levels of PHEV and EV adoption.

[24] *Emergency Economic Stabilization Act of 2008*, HR 1424, 110th Cong., 2nd Sess., (October 3, 2008): Doc. 110-343.

Chapter 5
Meeting the Mandates of the Energy Independence and Security Act of 2007

For the United States to be competitive in energy storage technologies, a focused implementation and deployment effort will be required by DOE, the electric power and transportation industries, and other impacted stakeholders. To ensure energy storage technologies' full potential and a leadership role for the United States, the government, utility, and transportation sectors must commit to such a sustained endeavor.

To meet the mandates of Subtitle D, Section 641(c)(4), of the Energy Independence and Security Act of 2007 (EISA), this chapter outlines a recommended five-year plan for integrating basic and applied research so that the United States retains a globally competitive domestic energy storage industry for electric-drive vehicles, stationary applications, and electricity transmission and distribution (T&D).

5.1 Research & Development Efforts

Making energy storage technologies a vital part of the nation's energy future starts with developing energy storage systems capable of satisfying practical applications. The demands of transportation energy storage applications with consistently high energy densities per unit of weight (in joules/kilogram and/or joules/cubic meter) will be more intense than those for electric power grid energy storage applications, in which cost is of greater concern than weight. The life cycle of electric vehicle (EV) batteries in terms of lifetime charge/discharge cycles will be dictated by expected vehicle warranty and lifetime considerations as well as the overall cost of driving the vehicle. By contrast, large-scale utility applications will place a higher value on reducing the technologies' costs and achieving the decades-long durability that utilities typically expect of their assets.

Therefore, the drivers for battery materials research for EV and utility applications diverge due to the priorities of different performance metrics. Today, utility energy storage technology applications are being piloted based on technology derived from EV-targeted applications, but the cost parameters limit the usefulness of these technologies to specialized ancillary services. Continued U.S. Department of Energy (DOE) efforts in materials research and energy storage technologies for central energy storage grid applications should be encouraged. Distributed energy storage opportunities offered by the transportation sector should be explored by DOE in the context of their potential uses in the electric power delivery system.

Although much of this report is focused on batteries, improving the performance of large-scale systems such as compressed air energy storage (CAES) should receive DOE support as well to ensure that the entire spectrum of energy storage devices is advanced. The areas of research and development (R&D) activities that should receive DOE attention are:

- Development of DOE-sponsored programs for rapid, systematic, and large-scale materials evaluation and screening tied to energy storage technology applications. These DOE programs should be designed to radically accelerate the screening process using supercomputer techniques to apply a "material genome" concept similar to that used with great success in the biological sciences.
- Establishment of the Centers of Excellence (COEs) currently under solicitation by the DOE Office of Science. DOE should provide long-term funding (at least 5 years) for these COE activities.
- DOE support for collaborative, interdisciplinary research between the national laboratories that support DOE, universities, and industrial partners such as automotive and utility technology centers.

5.2 Applied Research and Demonstration Activities

In the areas of new energy storage devices for utility and transportation applications, new energy storage systems are beginning to reach the market. The expansion of activities to test more applications at small and large scales needs to be supported by DOE and should include expanded DOE analysis of business cases and value propositions for energy storage technology applications of all types. These DOE-sponsored activities should include:

- Studies funded by DOE to consider the full scope of what is required to commercialize a domestic and international advanced battery market for vehicles, stationary applications, and utility applications. These studies should include the examination of all stages of market development from basic research to a functioning market, including comparing U.S. efforts with other countries to determine if there are market, institutional, or financial barriers and how best to remove them.
- Increased funding by DOE to accelerate the improvement in weight, size, cost, life, and safety of batteries for plug-in hybrid electric vehicles (PHEVs).
- DOE-funded demonstration activities that test the performance of Smart Grid technologies interacting with energy storage technologies on the grid. This effort should include PHEVs as a part of the load.
- DOE support for battery and flywheel energy storage applications for ancillary services use in frequency regulation of the grid. The applications should specifically target the use of energy storage technologies to provide a new short-term reserve product in the market intended to bridge the gap until additional traditional generation can be brought to the grid.
- DOE support for demonstration projects targeted at analyzing use of large-scale energy storage applications to reduce curtailment of wind power and other intermittent energy sources in areas with transmission constraints.
- DOE-funded demonstration projects in utility distribution networks to measure grid performance improvements regarding reduced T&D losses and system reliability improvement.
- DOE funding of development and demonstration of improved battery manufacturing techniques for PHEVs to ensure that an adequate domestic supply of batteries is available and to avoid replacing imported oil with imported batteries.

5.3 Recommended Plan for DOE Program Success

As with any complex program, measuring success is difficult, and metrics should be established to gauge progress. Actions to achieve the following recommended goals, if implemented, will ensure success of the DOE energy storage technology program:

Near-Term Goals (3–5 years)

- Launch and accomplish the "materials genome project" for analysis of alternative materials for use in energy storage devices.
- Complete detailed studies of the effects of higher penetration of renewable sources on grid operations and the permanent retirement of a large percentage of traditional generation.
- Complete at least three large-scale demonstration projects that examine the performance of Smart Grid technologies interacting with energy storage technologies on the grid.

- Establish the four Energy Storage Research Centers specified in the Energy Independence and Security Act of 2007.
- Provide funding for up to 30% of the cost of energy storage technology investments required to demonstrate the performance of the objectives cited above.

Mid-Term Goals (6–12 years)

- Continue to fund (up to 30%) energy storage projects that expand the use of storage for grid performance enhancement and show benefits to increasing the use of renewable energy resources.
- Measure and report the impact of PHEVs and EVs on performance of the grid in terms of peak loading and any change in the need for ancillary services.
- Fund next-step R&D activities based on the results from the "materials genome project" cited above.
- Fund larger-scale demonstrations of energy storage technologies for transportation to include large truck and rail applications.

Long-Term Goals (2020 and beyond)

- Implement programs to test and analyze vehicle-to-grid (V2G) performance and the impact on grid operations.
- Employ a public policy that establishes the desirability of maximizing the use of energy storage technologies for ancillary services provision, contributing to the development of energy storage for these applications.
- Establish a broad-based policy statement and programs aligned with that policy to bring electric energy capacity factors in line with other commodity productions, having significant long-term economic and societal benefits.

Chapter 6 Recommendations

Achieving the nation's goals of reducing dependence on fossil fuels and deploying a clean energy economy are enormous tasks that will require major technological innovation. Energy storage technologies will be major contributors in the transportation sector and will play a vital role in the electric power industry to help achieve those goals. Widespread deployment of energy storage technologies will require a three-pronged approach: (1) improved technologies that provide direct cost benefits to consumers and market opportunities for service providers; (2) financial incentives such as tax credits, and (3) mandated, time-based targets for the penetration of energy storage technologies, through mechanisms such as building codes.

To assist the U.S. Department of Energy (DOE) in accomplishing its goals to promote and develop cost-effective, innovative energy storage technologies, the Electricity Advisory Committee (EAC) provides the following recommendations:

1. Provide leadership in coordinating the completion of the mandates of the Energy Independence and Security Act of 2007 as defined in Chapter 5 of this report, particularly with respect to the research and development (R&D) and demonstration recommendations.
2. Create financial incentives, including ones applicable to non-profit utility entities, to help launch new storage applications for economics and reliability.
3. Guide the development of using energy storage as a primary source of frequency regulation control and possibly other ancillary services to replace the use of coal and natural gas-fired generation assets currently used in this application.
4. Establish a requirement that all long-term planning, including generation, transmission and distribution (T&D), demand-side resources, and renewable portfolio standards, specifically consider and address the deployment of energy storage technology as potential components of an integrated plan, considering the potential benefits identified in this report.
5. Commission an authoritative study to guide federal and state policymakers that quantifies the potential societal benefits of energy storage technologies. Such benefits include augmenting the usefulness and value of renewable energy resources and demand-side resources / load management, improving the capacity of the existing electric delivery system infrastructure, improving capacity factors of traditional generating resources, flattening electricity demand, and improving power quality and reliability. This effort should include the reuse of PHEV battery systems as storage devices in the grid after primary service in vehicles. It also should address the end-of-life disposal of storage media and "do-no-harm" policies with respect to environmental, public health, and safety considerations.
6. Promote public communications to raise awareness of the benefits of energy storage technologies to a level that is similar to public awareness of wind and solar power technologies. Such public education efforts should include the benefits of electric and hybrid vehicles

7. Encourage federal legislation to support applications of energy storage technologies by residential, commercial, and industrial consumers of electricity. For example, encourage the use of energy storage in the construction of new homes and commercial or industrial buildings, which would provide benefits such as reduced environmental impacts, improved energy independence, and improved reliability.
8. Carry out a focused education campaign. The DOE campaign should focus on educating power engineers and other stakeholders on the value and applications of electricity storage. DOE should approach land-grant universities for assistance in disseminating information about energy storage technologies and their application.

Chapter 7
References

The following documents have been considered and used as inputs to this report:

Institute of Electrical and Electronic Engineers, *Plug-in Electric Hybrid Vehicles* (Institute of Electrical and Electronic Engineers, June 15, 2007), Position Statement.

American Institute of Chemical Engineers, *Massive Electricity Storage* (American Institute of Chemical Engineers, June 2008).

Energy Security Leadership Council, "A National Strategy for Energy Security: Recommendations to the Nation on Reducing U.S. Oil Dependence," a project of Securing America's Future Energy White Paper, (Energy Security Leadership Council, September 2008).

Acronyms

AEP	American Electric Power
CAES	compressed air energy storage
CO_2	carbon dioxide
COE	Center of Excellence
DG	distributed generation
DOE	U.S Department of Energy
EAC	Electricity Advisory Committee
EISA	Energy Independence and Security Act
EMS	energy management system
EPRI	Electric Power Research Institute
EV	electric vehicle
GM	General Motors
GW	gigawatt
HEV	hybrid electric Vehicle
HVAC	heating, ventilation, and air conditioning
IEEE	Institute of Electrical and Electronics Engineers
ISO	Independent System Operator
kW	kilowatt
kWh	kilowatt hour
MW	megawatts
MWh	megawatt hour
NaNiCl	sodium nickel chloride
NaS	sodium sulfur
Ni	nickel
Ni-Cad	nickel-cadmium
Ni-MH	nickel-metal hydride
NO_x	nitrogen oxides
NYSERDA	New York State Energy Research and Development Authority
OEM	original equipment manufacturer
PHEV	plug-in hybrid electric vehicle
R&D	research and development
SO_x	sulfur oxides
T&D	transmission and distribution
UPS	uninterruptible power supply
V2B	vehicle-to-building
V2G	vehicle-to-grid
V2H	vehicle-to-home

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