Electric Power Storage

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Summary

Unlike natural gas or fuel oil, electricity cannot be easily stored. However, interest in electric power storage (EPS) has been growing with technological advancements that can make storage a more practical means of integrating renewable power into the electricity grid and achieving other operating benefits.

This report summarizes the technical, regulatory, and policy issues that surround implementation of EPS. Electricity storage is one of several non-traditional technologies and methods of meeting power demand that are of current congressional interest (others include distributed generation, renewable power, and demand response). EPS and these other alternatives do not fit the traditional power industry paradigm, which involves reliance on large-scale central power plants and long-distance transmission lines to meet demand. This raises the question of how quickly and effectively the power industry and its regulators will be willing to pursue and deploy new approaches. Electricity storage is also currently a relatively high-cost technology, another factor that could delay its deployment.

The report identifies several areas for possible congressional oversight, including:

- Power industry and state regulator acceptance of storage technologies.
- Integration of storage into transmission system planning, including integration of renewable power into the electricity grid.
- Federal executive agency focus on EPS as a solution to power system needs.
- The application of incentives for electric power storage development included in the American Recovery and Reinvestment Act of 2009 (ARRA; P.L. 111-5).

The report discusses how the provisions of several pending bills relate to the development of electric power storage, including S. 1091, the Storage Technology of Renewable and Green Energy Act of 2009 (STORAGE Act); H.R. 2454, the American Clean Energy and Security Act of 2009 (ACES); and S. 1462, the American Clean Energy Leadership Act of 2009 (ACELA).

This report will be updated as warranted.

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Introduction

Purpose and Organization

Unlike natural gas or fuel oil, electricity cannot be easily stored. However, interest in electric power storage (EPS) has been growing with technological advancements that can make storage a more practical means of integrating renewable power into the electricity grid and achieving other operating benefits.

This report summarizes the technical, regulatory, and policy issues that surround implementation of EPS. The report is organized as follows:

- This introductory section concludes with a brief discussion of certain key power system concepts.
- The next section describes EPS technology. This is followed by an analysis of barriers to the deployment of storage systems.
- The concluding section discusses areas of potential congressional interest, including oversight and current legislation.

Notes on Key Power System Concepts

Power Plants and Power Lines

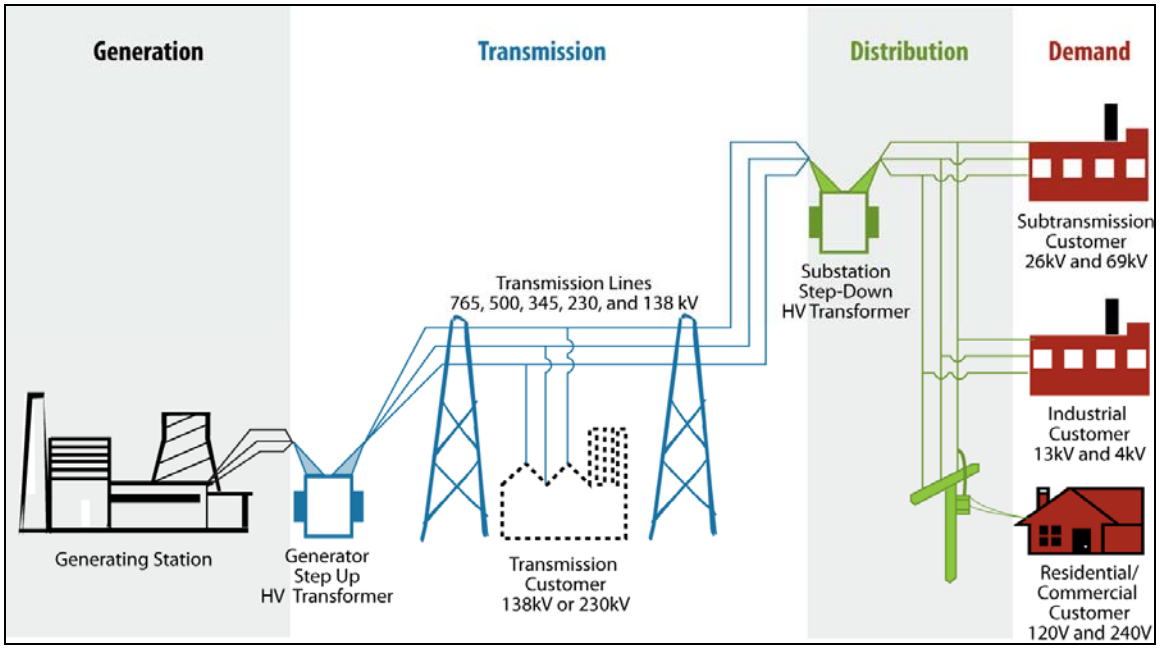
In addition to electric power storage, this report refers to power plants, transmission lines, and distribution lines. These facilities, which constitute the major components of the existing electric power system, are briefly described and illustrated below (**Figure 1**):

- *Generating plants* produce electricity, using either combustible fuels such as coal, natural gas, and biomass; or non-combustible energy sources such as wind, solar energy, and nuclear fuel.
- *Transmission lines* carry electricity from power plants to demand centers. The higher the voltage of a transmission line the more power it can carry. Current policy discussions focus on the high-voltage network (230 kilovolts (kV) rating and greater) used to move large amounts of power long distances.
- Near customers a step-down transformer reduces voltage so the power can be carried by low-voltage *distribution lines* for final delivery.

As discussed later in this report, EPS can be used throughout the power system, depending on the technology employed and the application.

Figure 1. Elements of the Electric Power System

Simplified Schematic



Source: CRS, based on graphic found at https://reports.energy.gov/BlackoutFinal-Web.pdf (p. 5).

Capacity and Energy

References will made in this report to megawatts and megawatt-hours. These are related but different concepts. A megawatt is a measure of a storage or generating unit's *capacity*, while a megawatt-hour is a measure of the unit's *energy* output.

Capacity is the potential instantaneous output of a generating or storage unit, measured in watts. Energy is the actual amount of electricity generated by a power plant or released by a storage device during a time period, measured in watt-hours. The units are usually expressed in thousands (kilowatts and kilowatt-hours) or millions (megawatts and megawatt-hours). For example, the maximum amount of power a 1,000 megawatt (MW) power plant can generate in a year is 8.76 million megawatt-hours (Mwh), calculated as:

1,000 MW x 8,760 hours in a year = 8.76 million Mwh.

EPS systems are sometimes discussed in terms of their capacity to energy ratios; that is, the ratio of peak instantaneous output (MW) to total energy released (Mwh) before the unit must be recharged. A high ratio indicates that the unit discharges rapidly, while a low ratio indicates that the unit releases its energy over a longer period of time.

Storage Technologies and Applications

Perhaps paradoxically, the storage of electricity does not usually involve the storage of the electric energy itself. Rather, the storage device converts the electricity to another form—such as

the kinetic energy in a spinning flywheel or the potential energy in water that has been pumped to a higher elevation—and then later converts the energy from the new form back to electricity.

With the exception of hydroelectric pumped storage, EPS technologies are still in various stages of development. This section of the report discusses the storage technologies and their applications. The technologies are summarized in **Table 1**.

Table 1. Electric Power Storage Technology Summary

Technology	Representative Applications	Energy Discharge Time Span	Status	Capacity
Hydroelectric Pumped Storage	Bulk power storage for peak shaving and load shifting, energy arbitrage, possible future applications supporting wind and solar generation.	Hours.	Commercial; 37 facilities are currently in operation in the United States.	Tens to hundreds of megawatts.
Compressed Air Energy Storage	Bulk power storage for peak shaving and load shifting, energy arbitrage, possible future applications supporting wind and solar generation.	Hours.	Commercial but with older technology (one unit apiece in Germany and Alabama); improved technology has been proposed.	Tens to hundreds of megawatts.
Stationary Batteries	Depending on the technology, batteries can be employed for frequency regulation, peak shaving and load shifting, backup power supply (islanding).	Milliseconds to minutes to a few hours, depending on the technology and application.	Pilot projects being installed, some without government funding, for sodium sulfur batteries. Research and development is continuing for this and other technologies.	Currently up to about one MW per unit. Multiple units can be combined to produce a larger installation, such as an existing 34 MW facility in Japan.
Plug-In Hybrid and Pure Electric Vehicles	Primary purpose is to power vehicles, but the stored power could also be used by power companies to meet emergency and peak demands	Hours.	Research and development.	Individually kilowatt scale, but cumulatively could amount to thousands of megawatts on a utility system.
Flywheels	Frequency regulation; spinning (emergency backup) reserve.	Milliseconds to minutes, depending on the application.	Pilot projects being installed.	About 25 KW per unit. Multiple units can be combined to produce larger installations, such as 20 MW facilities
Solar Thermal Storage	Bulk storage of energy produced by an integrated solar thermal plant. The stored energy can be employed to run the solar facility as a baseload, dispatchable station.	Hours.	Advanced development, including a project in Spain.	Tens to hundreds of megawatts.
Cooling Storage	Peak shaving and load shifting.	Hours.	Commercial.	Kilowatt-scale, but multiple units can be bundled by an aggregator for sale as a load management package to utilities.

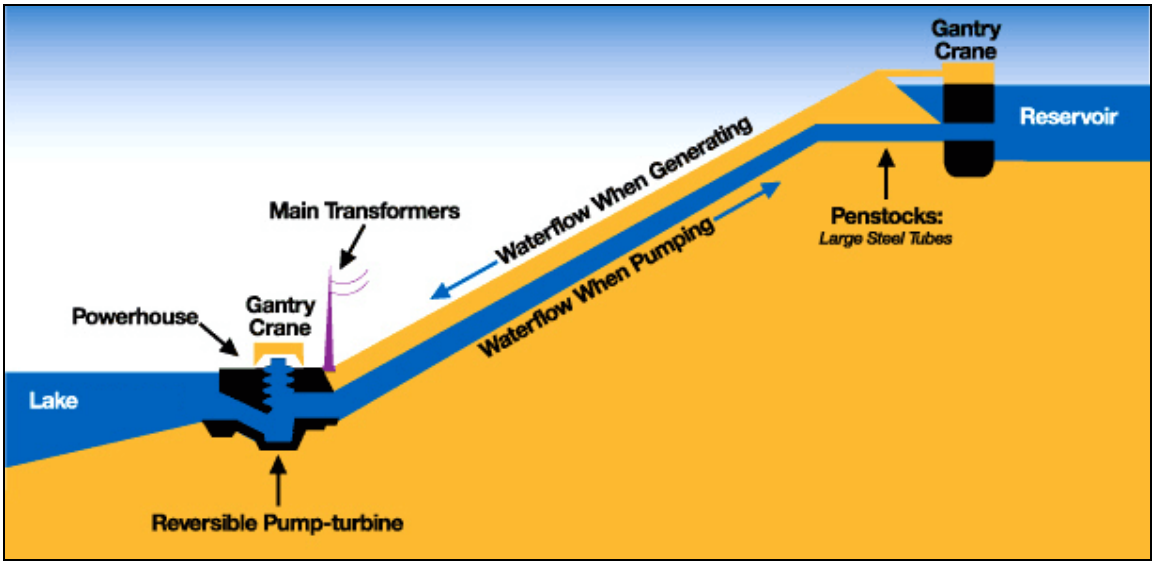
Source: CRS.

EPS technologies can be broadly categorized into two groups, each of which is discussed below: centralized bulk power storage and distributed storage. This section also discusses the relationship between EPS and the smart grid.

Centralized Bulk Power Storage

Centralized bulk power storage facilities are relatively large and complex installations designed to store large amounts of electricity. Capacities range from tens to hundreds of megawatts, and the units can supply power to the grid for hours at a time. The primary form of centralized bulk power storage—and in fact the only form of EPS of any type in commercial and widespread use—is hydroelectric pumped storage (HPS). In an HPS system, pumps are used during off-peak periods, when surplus cheap electricity can be generated elsewhere on the power system, to move water to a reservoir at a higher elevation than the water source. During peak periods, when power is scarce and expensive, the water in the reservoir is released to move backward through the system, where it drives hydraulic turbines to produce electricity. About 70% of the power used to pump the water up into the reservoir is recovered when the process is reversed (see **Figure 2**).

Figure 2. Hydroelectric Pumped Storage



Source: http://richard-rowland-perkins.com/professional/renewable-tech-hydropower/.

There are currently 37 operational HPS facilities in the United States with a total capacity of 19,696 MW. By comparison, total generating capacity in the United States is about 1 million MW.

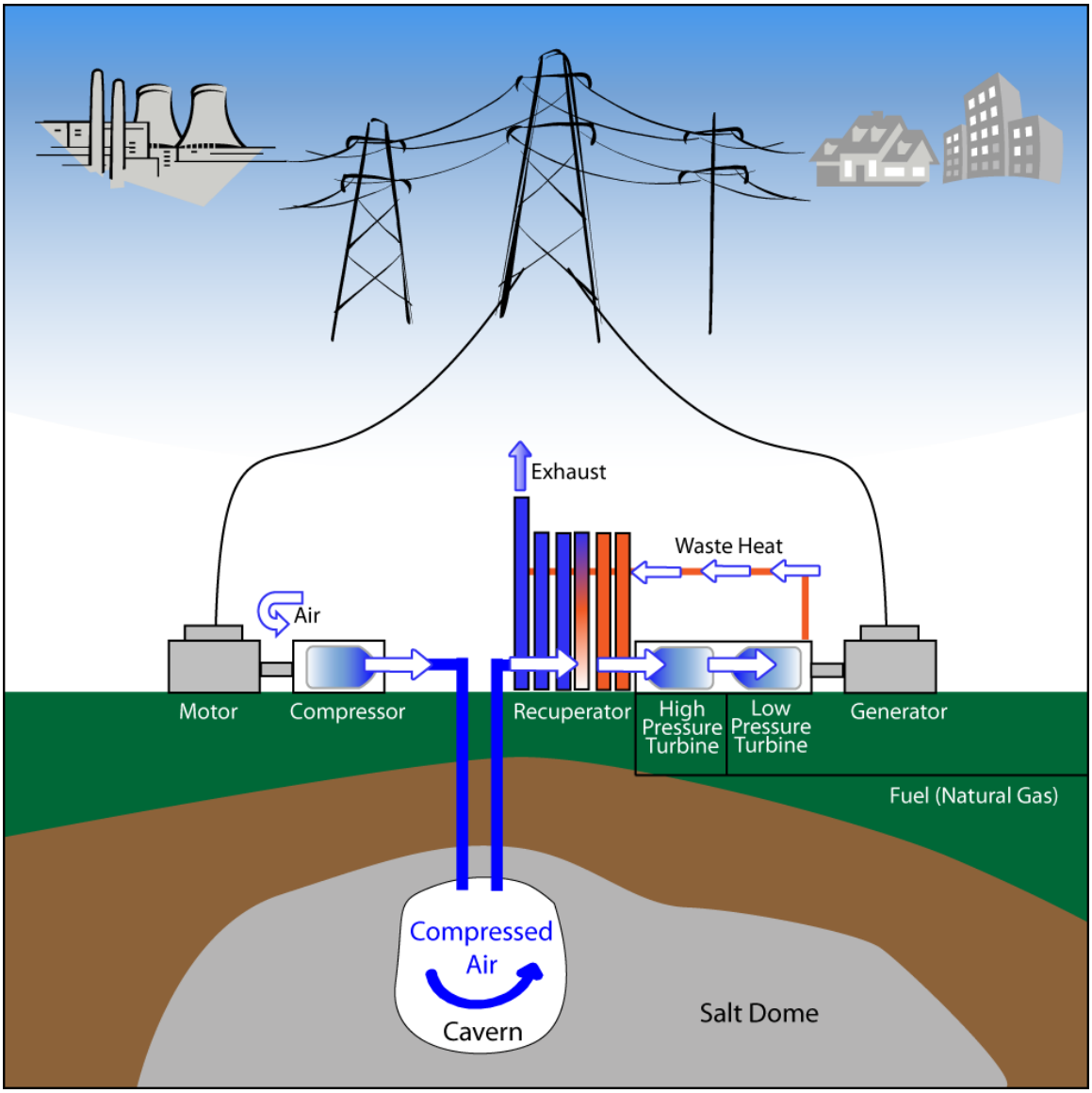
Of the 37 operational HPS facilities, 34 plants with 89% of the total capacity were built prior to 1991. The last facility was completed in 1995.[1] While plans have been discussed for additional projects it is unlikely that many more HPS facilities will be built. This is because the number of

[1] An additional HPS facility at the Richard B. Russell Dam and Lake in Georgia entered service in 2002 but the project was essentially complete years earlier. The situation at Russell is discussed later in the report.

suitable sites is limited and there are environmental objections to the construction of large hydroelectric projects.

The other form of centralized bulk power storage is compressed air energy storage (CAES). In this system compressors are used to inject air into a cavern developed within a salt dome or into another suitable geologic formation. To recover the power the compressed air is released, heated using a natural gas-fired combustion turbine, and used to help drive a turbine generator. A schematic of a CAES system is shown below (**Figure 3**).

Figure 3. Compressed Air Energy Storage



Source: CRS, based on a diagram at http://blogs.chron.com/newswatchenergy/archives/2007/07/power_for_when.html (citing Ridge Energy Storage and Grid Services).

Notes: For an animated version of this graphic, see http://ridgeenergystorage.com/.

Prototype CAES plants were built in 1978 in Germany (290 MW) and in 1991 in Alabama (the McIntosh plant, 110 MW). There are reportedly many sites in the United States suitable for construction of CAES units,[2] and because the units have a relatively small above-ground footprint they may face less public opposition than HPS developments. New projects have been announced but construction has not started.[3] The CAES technology is still evolving. For instance, the designers of the 1991 plant in Alabama are now seeking to build units using an improved "second generation" technology.[4]

One use of centralized bulk power storage systems is displacement of peaking generation. The cheap power captured in the facility during low-demand hours, such as the evening, can be used during the day to meet high loads in place of expensive-to-operate peaking power plants. An operationally related concept is price arbitrage, in which the cheap power stored at night is sold at a high price during the day.

A new potential use for centralized bulk storage would be to compensate for the variability in output from wind and solar plants. For example, in some parts of the country the strongest and most consistent winds blow at night when demand is low. This surplus wind power can be captured in a storage facility and then used to meet demand during the day. Stored electricity (captured from any generating source) can also be used to backstop wind and solar power if weather conditions are unfavorable. As discussed later in this report, the degree to which wind power in particular needs backup storage is disputed.

Distributed Power Storage

Distributed multipurpose power storage includes facilities dispersed through the power system and used to meet specific, local needs for power. The facilities can be located at generating plants, on the power transmission or distribution systems, or at an end-user site. The facilities are typically small but this may change as technologies mature. All of these technologies are still in the developmental stage.

The following distributed power storage technologies[5] and applications are discussed below:

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[2] Steve Blankinship, "Intermittent Wind: Problems and a Possible Solution," *Power Engineering*, June 2008. The article is available on-line by searching at http://pepei.pennnet.com/.

[3] This includes projects in Ohio, Iowa, California, and Texas. Samir Succar and Robert H. Williams, *Compressed Air Storage: Theory, Resources, and Applications for Wind Power*, Princeton University Environmental Institute, April 8, 2008, pp. 24-26, http://www.princeton.edu/~cmi/research/Capture/Papers/SuccarWilliams_PEI_CAES_2008April8.pdf. For information on the Iowa project, including an animated description of the proposed facility, see http://www.isepa.com/index.asp. Most recently, on August 26, 2009, Pacific Gas & Electric Co. in California announced it was seeking $25 million in federal stimulus funding to help fund a 300 MW, $356 million CAES facility in Kern County. The project would take five years to design and build, and would have 10 hours of capacity. The primary source of stored electricity would be wind power. For more information see the posting at the utility's website, http://www.next100.com/, and Tracy Seipel, "PG&E to Build Plant to Store Wind Energy," *San Jose Mercury News*, August 27, 2009.

[4] See the website for Energy Storage and Power LLC at http://www.energystorageandpower.com/home.html.

[5] Other technology options include ultracapacitors and superconducting magnetic energy storage devices. These are still in an early developmental stage and reportedly not ready for utility-scale power system applications (Rahul Walawalkar, Jay Apt, and Rick Mancini, "Economics of Electric Energy Storage for Energy Arbitrage and Regulation in New York," *Energy Policy*, April 2007). For additional information on these technologies see American Physical Society, *Challenges of Electricity Storage Technology*, May 2007, http://www.aps.org/policy/reports/popa-reports/upload/Energy-2007-Report-ElectricityStorageReport.pdf.

(continued...)

- Batteries.
- Flywheels.
- Solar thermal storage.
- Residential electricity storage.
- Commercial-scale cooling storage.
- Storage and the smart grid.

Batteries

Although battery technology is still under development, commercial applications exist in the United States and elsewhere. **Figure 4** shows a 34-MW battery facility in Japan used in conjunction with a 51-MW wind farm. The facility uses sodium sulfur (NaS) batteries produced by a Japanese manufacturer, NGK Insulators.

Figure 4. Japanese 34 MW Battery Facility for Use with a Wind Plant

Source: http://www.ngk.co.jp/english/products/power/nas/installation/index.html.

American Electric Power (AEP), a large domestic power company, deployed a 1-MW NaS battery (the size of a double-decker bus and weighing 77 tons) in 2006 in Charleston, WV. The project was funded in part by the Department of Energy (DOE). The battery was connected to the distribution system and is charged in the evening when demand is low; by providing power as needed during higher-demand daytime periods it alleviates an overloading problem and defers the

(...continued)

need to build a new substation. In 2008 AEP installed two 1-MW batteries near Milton, WV, to relieve another distribution system overloading problem.[6]

Other existing or planned battery installations include:

- AES Energy Storage, an affiliate of the large power project developer AES Inc., has connected a 1-MW array of batteries carried in a truck trailer to the grid in Pennsylvania, and a similar 2-MW array at a wind farm it owns in California. These projects use lithium ion technology supplied by A123Systems in Massachusetts.
- Xcel Energy, a Midwestern utility, is testing a trailer-carried 1-MW NaS battery at a wind farm it owns in Minnesota. The project has government and university partners.[7]
- AEP installed three facilities of 2 MW each at sites in Ohio, West Virginia, and Indiana in 2008, and a 4-MW facility in Texas in 2009. The company reportedly aims to install 1,000 MW of battery capacity throughout its system by 2020.[8]
- The New York Metropolitan Transit Authority installed a 1-MW NaS battery in January 2009. The battery stores inexpensive off-peak power in the evening to run natural gas compressors used for refueling buses during the day. The installation is a demonstration project funded in part by the state and federal governments and industry trade associations.[9]

Batteries can provide several different services to the power system. Depending on the technology,[10] batteries can provide a local source of power for several hours, displacing or deferring the need for additional generating, transmission, or distribution capacity; provide a backup source of power to a local area if other parts of the grid fail (referred to as "islanding"); and provide grid "regulation," a service described immediately below in the flywheel discussion.

[6] Statement of Larry Dickerman, Director, Distribution Engineering Services, American Electric Power, before the House Committee on Science and Technology, Subcommittee on Energy and Environment, October 3, 2007; George Hohmann, "Utility Installs Giant Batteries in Milton; Devices Can Store Enough Energy to Supply 760 Households for Six to Seven Hours," *Charleston (West Virginia) Gazette*, December 18, 2008.

[7] "News Briefs: Xcel Energy," *Platts Electric Utility Week*, April 20, 2009.

[8] Jeff Ryser, "Electricity Storage Technology Moves Forward with Support by Grid Operators," *Platts Electric Utility Week*, April 6, 2009; Ali Nourai, AEP, "Massive Electricity Storage: A Utility Perspective," Congressional briefing for the Energy Storage Association, Washington, DC, June 16, 2009, slide 3; AEP, "Electric Transmission Texas Signs Contract for Largest Utility-scale Battery in the U.S.," press release, September 1, 2009, http://www.aep.com/newsroom/newsreleases/?id=1560.

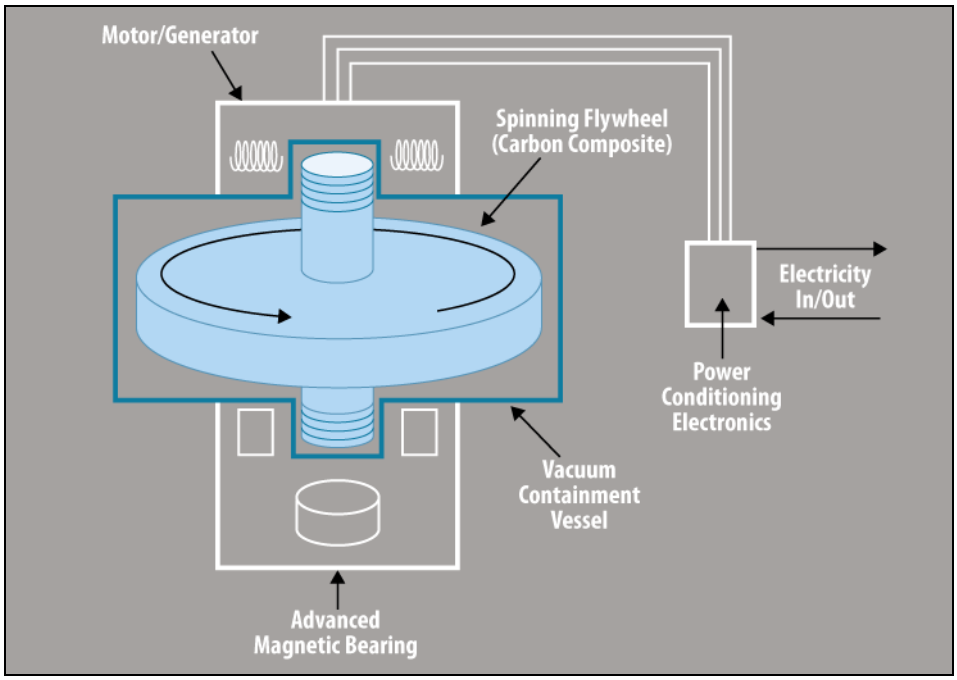
[9] New York Metropolitan Transit Authority, "MTA LI BUS And NYPA Install First Sodium Sulfur Battery Energy Storage System In State," press release, January 9, 2009, http://www.mta.info/mta/news/releases/?en=090109-HQ2.

[10] Battery technology continues to evolve and designs other than the NaS and lithium ion systems mentioned above are under development. For additional information on battery technologies see the website of the Energy Storage Association at http://www.electricitystorage.org/site/technologies/; American Physical Society, *Challenges of Electricity Storage Technology*, May 2007, http://www.aps.org/policy/reports/popa-reports/upload/Energy-2007-Report-ElectricityStorageReport.pdf; and Jonathan Shieber, "Producers – Building a Better Battery," *The Wall Street Journal*, November 17, 2008.

Flywheels

A flywheel stores electricity in the form of mechanical energy in a spinning wheel or tube. In storage mode power is used by a motor to spin-up the flywheel. To recover power, the flywheel drives a generator (**Figure 5**). About 85% to 90% of the stored power can be recovered.[11]

Figure 5. Flywheel Electricity Storage



Source: CRS, based on a schematic at http://www.dg.history.vt.edu/ch2/storage.html.

With current technology individual flywheel units have a capacity of about 25 kilowatts (kw). These can be deployed in integrated arrays to produce megawatt-scale installations. Beacon Power, a Massachusetts firm, is currently operating a 2-MW pilot facility in that state and hopes to expand to 5 MW by the end of 2009. The firm has also received a $2 million grant from New York State and tentative approval for a $43 million federal loan guarantee to help support construction of a 20-MW plant in New York.[12] A 1-MW facility is being planned in conjunction with AEP for installation in Ohio.[13]

These projects are intended to provide regulation service to the power grid, a service which, as noted above, can also be provided by battery facilities. In this context "regulation" refers to the need for power grid operators to precisely match, moment to moment, the supply and demand for electricity. If supply and demand go too far out of synch, the power system can become unstable,

[11] For more information on flywheel technology, see Ed Douglas, "New Generation Flywheels," *Power Engineering*, May 2009 and Steve Blankinship, "Megawatt-Scale Flywheel Nears Market Readiness," *Power Engineering*, April 2007 (the articles can be found on-line by searching at http://pepei.pennnet.com/); and American Physical Society, *Challenges of Electricity Storage Technology*, May 2007.

[12] See press releases on the Beacon Power website at http://www.beaconpower.com/company/news.asp.

[13] "Beacon Power Building Energy Storage Facility at AEP Site," *The Energy Daily*, February 24, 2009.

consumer electrical equipment and appliances can be damaged, and ultimately the grid can fail. Because demand is constantly changing, the output of some power plants on a power system is constantly varied, up and down, to match demand. Because power plants generally operate most efficiently at a steady state, constant small-scale adjustments increase fuel costs and wear and tear on the generators.

Although current flywheels can provide power for up to 15 minutes, regulation depends on their moment-to-moment ability to move power on and off of the grid. The need for regulation service may increase in the future as more wind and solar power with variable, weather-dependent output is connected to the power system.[14] Regulation service from conventional generators has worked reliably for decades, but in principle a storage device such as a flywheel or battery could provide the service more efficiently. Flywheels and some types of batteries are EPS options for providing this capability.

Another service that is essential to maintaining the stability of the grid is reactive power supply. As explained by the Federal Energy Regulatory Commission (FERC):

> Almost all bulk electric power in the United States is generated, transported and consumed in an alternating current (AC) network. Elements of AC systems produce and consume two kinds of power: real power (measured in watts) and reactive power (measured in volt-amperes reactive, or var). Real power accomplishes useful work (e.g., running motors and lighting lamps). Reactive power supports the voltages that must be controlled for system reliability.
>
> Reactive power supply is essential for reliably operating the electric transmission system. Inadequate reactive power has led to voltage collapses and has been a major cause of several recent major power outages worldwide. And while the August 2003 blackout in the United States and Canada was not due to a voltage collapse as that term has been traditionally used, the final report of the U.S.-Canada Power System Outage Task Force (April 2004) said that "insufficient reactive power was an issue in the blackout." Dynamic capacitive reactive power supplies were exhausted in the period leading up to the blackout.[15]

Although generating plants produce real and reactive power, additional reactive power must be injected at various points throughout a power grid. This is currently accomplished by specialized devices, but flywheels are another potential option.

Solar Thermal Storage

Solar thermal and photovoltaic power are alternative means of harnessing sunlight to produce electricity. Photovoltaic power, probably the better-known technology, uses solar cells to directly convert sunlight to electricity. Solar thermal plants, also referred to as concentrated solar power (CSP), concentrate sunlight to heat a working liquid, such as water, to produce steam that drives a power-generating turbine.[16] Several parabolic trough-type CSP installations have operated

[14] Richard Fioravanti, Khoi Vu, and Walter Stadlin, "Large Scale Solutions," *IEEE Power and Energy*, July/August 2009, p. 50.

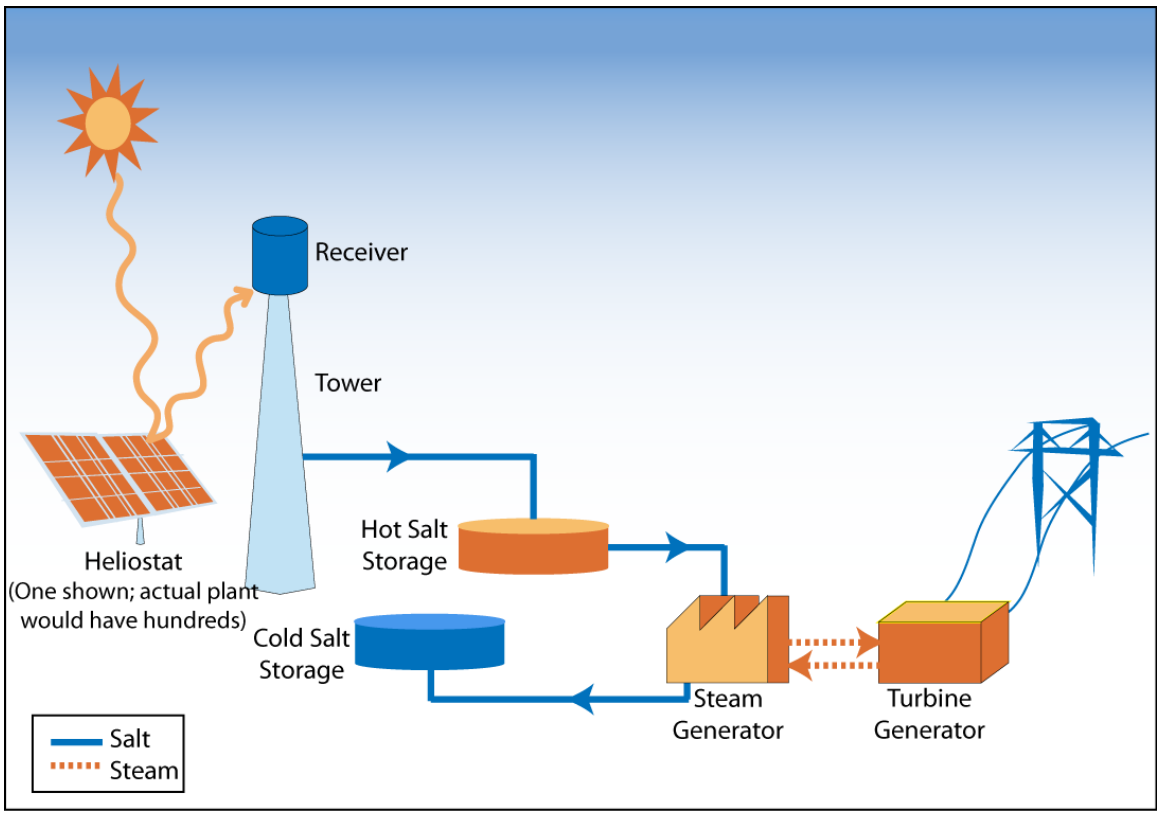
[15] FERC, *Principles for Efficient and Reliable Reactive Power Supply and Consumption*, Staff Report, Docket AD05-1-000, February 4, 2005, p. 3, http://www.ferc.gov/eventcalendar/files/20050310144430-02-04-05-reactive-power.pdf.

[16] The two major types of solar thermal systems are parabolic trough and power tower technologies. Parabolic trough plants use an array of mirrors to focus sunlight on liquid-carrying tubes integrated with the mirrors. The power tower technology uses a mirror field to focus sunlight on a central tower, where the heat is used to produce steam for power (continued...)

successfully in California since the 1980s, and the 64-MW Nevada Solar One plant began operating in 2007.

Several new solar thermal projects, with capacities in the hundreds of megawatts, are in development. A potential advantage of solar thermal systems is the ability to produce electricity when sunlight is weak or unavailable by storing solar heat, such as in the form of molten salt. In such a system the concentrated solar energy is used to melt salts (such as sodium and potassium chloride). A heat exchanger (also referred to as a steam generator) is used to capture heat from the salt to produce steam, which then drives a power turbine (**Figure 6**). Reportedly up to 93% of the stored energy can be recaptured for steam production.[17]

Figure 6. Schematic of a Solar Thermal Power Plant with Molten Salt Storage



Source: CRS, based on a diagram at http://thefraserdomain.typepad.com/energy/2005/09/aabout_solar_to.html.

Notes: A heliostat is a mirror that reflects solar rays onto a central receiver. A heliostat automatically adjusts its position to track daily or seasonal changes in the sun's position. The arrangement of heliostats around a central receiver is also called a solar collector field. (Definition from http://www.eia.doe.gov/glossary/index.html.)

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generation. A research power tower, the Solar One/Two plant, operated for several years in the 1980s and 1990s in California. A power tower plant has recently been constructed in Spain and projects have been proposed for the United States. For more information see CRS Report RL34746, *Power Plants: Characteristics and Costs*, by (name reda cted).

[17] For additional information on CSP and thermal storage technology see David Bello, "How to Use Solar Energy at Night," *Scientific American*, February 18, 2009, http://www.scientificamerican.com/article.cfm?id=how-to-use-solar-energy-at-night.

Molten salt storage was used at the test Solar One/Two plant in the United States, and is being used now at the 50-MW Andasol 1 plant in Spain (a second 50-MW block is under construction and a third is planned). The Spanish plant can run at full load for 7.5 hours using stored heat. The disadvantage of adding molten salt storage to a CSP plant is the additional cost and complexity. For example, the developer of the 400-MW Ivanpah CPS project in California decided not to use molten salt storage in the project in order to reduce costs and make the project "commercially viable by getting rid of the extras." The decision on whether to add storage to a project pivots on the balance between the incremental costs and the additional revenues available by being able to provide firm service over an extended operating day.

Residential Electricity Storage

Batteries can be used to store electricity in individual homes, either in battery banks or in the battery packs of plug-in hybrid electric vehicles (PHEV), or at small sites serving a group of homes. Each approach has different technical and economic issues.

Fixed in-home storage involves installing a bank of batteries in the house, and is often discussed in conjunction with installing a home solar photovoltaic (PV) system. The idea is that surplus PV power generated during the day can be stored and used when less sunlight is available or home demand is high. With current battery technology these systems can be bulky, require power conversion electronics, and require significant maintenance and replacement time and expense.[18] More advanced battery technology could reduce costs and improve performance.

PHEVs have battery packs that can be charged through a home's power system. As with fixed in-home battery banks, the notion is to use off-peak power to charge the battery. These systems and the vehicles that would use them are still under development but have garnered a great deal of interest and government and industry attention.[19]

The interaction between in-home storage and the power system is complex. The electricity stored in the batteries can be viewed as a resource only for and under the control of the homeowner. An alternative concept, which is closely tied to the notion of a smart grid (discussed below), is that the utility would have control over the operation of the batteries. For example, utility control of a large network of distributed batteries could allow the utility to rely on power stored in the batteries during off-peak hours, such as the evening, to meet daily peak demands. This approach requires less construction of transmission and generation facilities than with traditional utility methods. However, it also means that the utility and not the homeowner would have control over charging and discharge cycles.

Utility control may be problematic in particular for PHEVs, since a homeowner planning a relatively long late afternoon trip may not want the utility taking power out of his or her vehicle's battery pack to meet mid-day system peaks. On the other hand, some degree of utility control

[18] National Renewable Energy Laboratory, "Battery Power for Your Residential Solar Electric System," October 2002, http://www.nrel.gov/docs/fy02osti/31689.pdf.

[19] For additional information see the discussion of "Economics of Plug-In Hybrid Electric Vehicles" in EIA, Annual Energy Outlook 2009, pp. 31-35, http://www.eia.doe.gov/oiaf/aeo/index.html. A recent DOE study notes that "PHEVs are unlikely to play a significant role as a storage mode or as a distributed generator in the near term due to cost considerations." DOE, *Smart Grid System Report*, July 2009, p. 20, http://www.oe.energy.gov/DocumentsandMedia/SGSRMain_090707_lowres.pdf.

and/or government regulation will be needed to prevent situations where homeowners try to charge PHEV batteries during peak periods, which would increase system costs and perhaps degrade system reliability.

In-home storage also competes with the concept of "net metering." Net metering provides for a utility to buy surplus power generated by the home PV system (or other generating system).[20] The system owner then receives either a cash payment or electricity in kind when home demand exceeds PV output. Net metering arrangements vary by locality and may provide superior economics to home power storage.[21]

Multi-home electricity storage involves a small battery facility that would serve several homes, perhaps half-a-dozen, with several hours of storage. The facility would be owned, controlled, and maintained by the local utility, and would be used for peak shaving, as a backup power supply,[22] and for power quality control.[23] This kind of centralized facility would presumably benefit from economics of scale compared to individual home battery banks, but the homeowner would also lose control of the storage. Additional metering, wiring, and billing enhancements would be needed for a centralized facility to be used to collect surplus power from a home's PV system and send it back when needed.

Commercial-Scale Cooling Storage

Cooling storage devices use electricity during non-peak hours, such as the evening, to turn water to ice. During the day and particularly at times when electricity demand would normally be at its peak, such as midday or the afternoon on a summer business day, the ice can be used to cool air, displacing air conditioning load. This type of storage is currently economical for commercial and industrial establishments, such as office buildings. Cooling storage is a commercial technology sold by several vendors.

Cooling storage affects the power system by *shaving peak demand* and *shifting load*. As shown below in **Figure 7**, by cutting air conditioning load during the day the cooling storage cuts peak demand. This reduces the need to operate, or even to build, some relatively high-priced natural-

[20] Net metering is defined more fully at the Database of State Incentives for Renewables & Efficiency (http://www.dsireusa.org/glossary/): "For electric customers who generate their own electricity, net metering allows for the flow of electricity both to and from the customer—typically through a single, bi-directional meter. With net metering, during times when a customer's generation exceeds the customer's use, electricity from the customer flows back to the grid, offsetting electricity consumed by the customer at a different time. In effect, the customer uses excess generation to offset electricity that the customer otherwise would have to purchase at the utility's full retail rate. Net metering is required by law in most U.S. states, but some of these laws only apply to investor-owned utilities – not to municipal utilities or electric cooperatives."

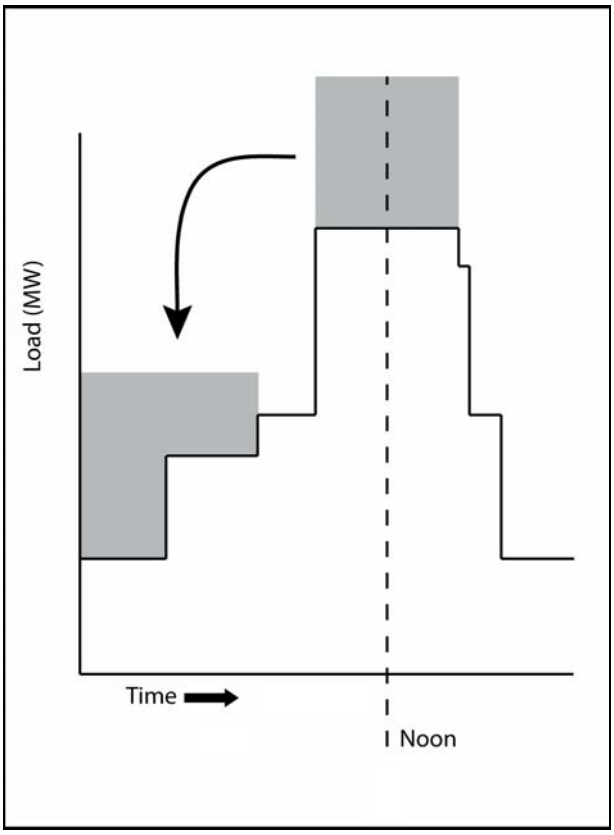
[21] For state level implementation information, see the Database of State Incentives for Renewables & Efficiency at http://www.dsireusa.org/summarytables/rrpre.cfm. For a brief comment on home storage versus net metering, see http://energyoutlook.blogspot.com/2009/03/storing-sunlight.html.

[22] According to AEP, just four hours of storage would cover about 90% of the utility's power outages. Martin LaMonica, "Utility AEP Plans Backyard Energy Storage," *CNET News: Green Tech*, March 7, 2009, http://news.cnet.com/8301-11128_3-10191231-54.html.

[23] AEP is reportedly planning to install multi-home storage systems, perhaps using lithium ion battery technology. "AEP to Install Residential Energy Storage," Pennwell Power Group On-Line Article, March 19, 2009, http://pepei.pennnet.com/Articles/Article_Display.cfm?Section=ARTCL&PUBLICATION_ID=6&ARTICLE_ID=356711&C=INDUS&dcmp=rss; and "FERC Examining First-Ever Comprehensive Storage Pricing Policy," *Energy Washington Week*, July 29, 2009.

gas-fired peaking plants. However, the load is not eliminated, but shifted to the non-peak hours when the storage system makes ice.

Figure 7. Schematic of Peak Shaving and Load Shifting



Source: CRS, based on a diagram at http://oee.nrcan.gc.ca/publications/infosource/pub/cipec/efficiency/2_04.cfm?attr=20.

The effect of the load shifting and peak shaving is likely to be a reduction in total costs to consumers. This is for three reasons:

- The shifted load would be met in most utility systems by coal or natural gas combined cycle plants that are under-utilized in the evening. These are cheaper to operate than peaking plants. However, to the extent that carbon dioxide emissions are a concern, shifting more load to coal-fired plants may be an issue.
- In restructured markets,[24] power prices for all generators are set by the price of the marginal—that is, highest priced—generating unit to operate during a certain time period, such as hourly. By reducing the peak load on generating units, and

[24] In restructured power markets, retail rates for electricity reflect daily market bids for electricity supply in the wholesale market. In traditional markets, rates are set by state utility commissions. Neither market is deregulated, but the forms of regulation are much different. Many states in the Midwest, Northeast, New England, Texas, and California have adopted various forms of restructured markets while other parts of the county, particularly the Southeast and Northwest, continue to rely on traditional rate regulation. For additional background see DOE, *Keeping the Lights on in a New World*, January 2009, pp. 18-23, http://www.oe.energy.gov/eac.htm.

therefore the need to operate higher-cost peaking units, peak shaving can have a substantial impact on total power costs.[25]

- Making ice during relatively cooler evening hours is somewhat more efficient than running air conditioning during the hottest daytime hours. This efficiency gain can essentially eliminate any power losses in the storage process.[26]

The economics of cooling storage can be improved by a load management "aggregator." The aggregator is a kind of broker that combines the capacity of multiple cooling storage installations into a block that can be sold to a utility as a single, guaranteed load management resource.

Cooling storage is limited to the cooling season and by the amount of capacity that can be installed, which is a function of the amount of air conditioning load in suitable buildings. In climates that experience high summer and winter demand it would be preferable to have storage that can shave peaks year-round.

Storage and the Smart Grid

Power grid modernization proposals are often made under the rubric of the "smart grid," a term that encompasses technologies that range from advanced meters in homes to advanced software in transmission control centers. There is no standard definition of the smart grid.[27] For the purposes of this report, the smart grid can be viewed as a suite of technologies that give the grid the characteristics of a computer network, in which information and control flows between and is shared by individual customers and utility control centers. The technologies would allow customers and the utility to better manage electricity demand, and include self-monitoring and automatic-protection schemes to improve the reliability of the system.[28] Although grid technology has not been static over the years,[29] the smart grid concept would implement capabilities well beyond any existing electric power system.[30]

The smart grid involves integrated operation of the power system from the home to the power plant and could encompass management of centralized and distributed EPS. In principle a smart grid system would optimize the full range of available resources—including the various kinds of distributed storage and net metering distributed generation—to meet multiple needs, including

[25] Storage units like batteries and CAES can supply during peak hours relatively inexpensive electricity stored in the evening, putting further downward pressure on peak-hours prices. See Motion to Intervene and Comments of Xcel Energy Services Inc., Before the Federal Energy Regulatory Commission, Docket No. ER09-1126-000, June 2, 2009, p. 14 (available through FERC docket search at http://elibrary.ferc.gov/idmws/docket_search.asp).

[26] Michael T. Burr, "Storage Goes Mainstream," *Public Utilities Fortnightly*, April 2009, p. 29.

[27] DOE's Electricity Advisory Committee noted that "there are many working definitions of a Smart Grid." Electricity Advisory Committee, *Smart Grid: Enabler of the New Economy*, U.S. Department of Energy, Washington, DC, December 2008, p. 1.

[28] Other descriptions of the smart grid emphasize its environmental benefits through reducing fossil-fueled electric generation and air pollution emissions. See the comments of FERC Commissioners Moeller and Spitzer in Federal Energy Regulatory Commission, "FERC Accelerates Smart Grid Development with Proposed Policy, Action Plan," press release, March 19, 2009, http://www.ferc.gov/news/news-releases/2009/2009-1/03-19-09.asp.

[29] Scott Gawlicki, "Demonstrating the Smart Grid," *Public Utilities Fortnightly*, June 2008, p. 51; and Kenneth Martin and James Carroll, "Phasing in the Technology: Phasor Measurement Devices and Systems for Wide-Areas Monitoring," *IEEE Power and Energy*, September/October 2008.

[30] For additional information on the smart grid and the transmission system generally see CRS Report R40511, *Electric Power Transmission: Background and Policy Issues*, by (name redacted).

peak shaving, backup power in the case of outages, electricity regulation, and ensuring that distributed battery systems are charged during non-peak hours.

The close relationship between the development of storage and the smart grid is reflected in the smart grid policy statement recently promulgated by FERC. The policy identifies EPS as one of "four key functionalities" that the smart grid must implement.[31] A recent DOE report finds that:

> The ability to accommodate a diverse range of generation types, including centralized and distributed generation as well as diverse storage options, is central to the concept of a smart grid. Through these generation and storage types, a smart grid can better meet consumer load demand, as well as accommodate intermittent renewable-energy technologies. Distributed resources can be used to help alleviate peak load, provide needed system support during emergencies, and lower the cost of power provided by the utility.[32]

The report also observes that many technical challenges remain before the smart grid and associated technologies can be fully deployed, noting that "accommodating a large number of disparate generation and storage resources requires anticipation of intermittency, unavailability, while balancing costs, reliability, and environmental emissions."[33]

Like electricity storage, the smart grid is for the most part a developmental rather than operational technology. Other than installation of smart meters in some localities (which permit interactive communication and in some cases appliance control between homes and utility control centers) deployment of the "full" smart grid, which would include optimization of storage and other resources, has not progressed beyond pilot projects.

Barriers and Issues in Deploying Electric Power Storage

EPS does not fit neatly into traditional utility planning, or current regulatory and financing structures, which have approached power system needs with central station power plants and large transmission projects. As one analysis notes:

> We know from years of operating pumped hydroelectric facilities that incorporating them into market and grid operations is a nontrivial task. Optimally scheduling the use of these facilities in a market with dynamic pricing can be a complicated problem. There are not so many of these facilities in use, however, that the problems have had to be generally solved for scale application. Today, though, we can foresee a future with many electric storage systems out there—at wind farms and other generation sites, grid-connected at transmission and distribution substations, and deployed along distribution feeders and behind the meters. Storage will represent a new class of electric infrastructure apparatus and will require that we develop new algorithms, tools, protocols, and regulatory paradigms for planning, financing,

[31] The others are wide-area situational awareness, demand response, and electric-powered transportation. The policy also identifies two "cross-cutting issues," cybersecurity and a common information model. For additional information see the proposed and final policy statements (dated, respectively, March 19 and July 16, 2009), available by searching for Docket No. PL09-4-000 at http://elibrary.ferc.gov/idmws/docket_search.asp.

[32] DOE, *Smart Grid System Report*, July 2009, p. 18, http://www.oe.energy.gov/DocumentsandMedia/SGSRMain_090707_lowres.pdf.

[33] Ibid.

> and operating these assets. The greatly increased flexibility that storage brings to the electric system will best be exploited only when we have the right new methods and understanding in place.[34]

This section of the report discusses environmental, cost, regulatory, and institutional issues which may impede the deployment of EPS systems.

Environmental and Cost Factors

The only EPS technology that is both technically mature and widely used is hydroelectric pumped storage. However, there will probably be few opportunities to build more HPS plants in the United States. Two limiting factors are lack of suitable site and high cost. As shown in **Table 2**, the estimated cost of building a new HPS facility is $2,500 to $4,000 per KW of capacity, exclusive of financing (which can be very significant) and certain other costs (see the notes to the table). This is, roughly speaking, in the range of costs for building a new coal plant at the low end ($2.5 billion) and a new nuclear power plant at the high end ($4 billion). Perhaps even more important than the cost of HPS are the perceived environmental impacts, including flooding of valleys to create reservoirs and damage to wildlife habitats. Environmental objections to HPS are so severe that they have delayed the operation of completed plants. For example, an HPS facility at the Richard B. Russell Dam and Lake in Georgia was essentially completed in the mid-1980s, but did not enter service until 2002 due to environmental litigation and related testing.[35] The HPS capacity at the Harry S. Truman Dam and Reservoir in Missouri has never been used commercially for environmental reasons.[36]

Table 2. Electric Power Research Institute Estimates of Capital Costs for Electric Power Storage Technologies

Technology	Technology Detail	Current or Projected Cost	Estimated Total Capital Cost, $ per Kilowatt of Capacity
Compressed Air Energy Storage	100 to 300 MW facility; underground salt dome storage	Current	$600 to $750
Hydroelectric Pumped Storage	1000 MW	Current	$2,500 to $4,000
Battery—Conventional	Sodium Sulfur	Projected	$1,850 to $2,150
Battery—Advanced	Flow Battery	Projected	$1,545 to $3,100
Flywheel	10 MW facility	Current	$3,695 to $4,313

Source: Dan Rastler, "The Electric Storage Landscape: Renewables Integration and Smart Grid," presentation, *Platts Power Storage Conference*, January 15-16, 2009.

[34] Ralph Masiello, "Bottling Electricity," *IEEE Power and Energy*, July/August 2009, p. 24.

[35] Southeastern Power Administration, "Hydropower Pump-back Projects/Perspectives," presentation, Southwestern Federal Hydropower Conference, June 10, 2009, http://www.swpa.gov/PDFs/2009Conference/Pumpback-PMA-Perspective-Nadler.pdf; and http://www.sjrdotmdl.org/Meeting_info/mW6s3bb.doc.

[36] General Accounting Office, *Power Marketing Administrations: Cost Recovery, Financing, and Comparison to Nonfederal Utilities*, September 1996, p. 34, http://www.gao.gov/archive/1996/ai96145.pdf.

Notes: The EPRI source material notes (1) all figures are rough order-of-magnitude estimates; (2) total capital costs include power conditioning system and all equipment necessary to supply power to the grid; (3) not included are battery replacement costs, site permitting, interest during construction and substation costs; and (4) the cost estimates are for mid-2008.

Other storage technologies do not have the same environmental issues as HPS (although issues may arise if storage systems become more common[37]), but they appear to share the HPS issue of high cost. The Electric Power Research Institute (EPRI) capital cost estimates shown in **Table 2** are roughly comparable to those of the current range of conventional fossil and nuclear generating technologies.[38] However, the operating times of conventional power plants are, with the exception of peaking units, measured in days and months, rather than the hours and minutes of storage technologies. Also, storage systems generally return to the grid less power than they store. Consequently, storage devices have fewer kilowatt-hours of output to spread their costs over than conventional generators, which increases the cost per kwh. The **Table 1** estimates, which EPRI is planning to update in a more comprehensive form by the end of 2009,[39] also do not account for maintenance, battery replacement, and financing expenses.

Storage technology continues to evolve and with more advanced systems and economies of scale from mass production the costs could decline. Nonetheless, for the time being it seems fair to treat EPS as generally a high-cost suite of technologies. There are current federal incentives and grants that can help to compensate for these high costs, as discussed later in the report. But for a long-term and sustainable role in the power system, it appears that storage will need revenue from premium applications, and revenue from multiple value streams that reflect the many uses to which storage can be put. For example, a flywheel facility might provide:

- Regulation service, which according to one analyst may produce system benefits 5 to 10 times greater than peak shaving and load shifting.[40]
- Emergency backup reserve power to the grid (referred to as "spinning reserve") for short periods.
- Reactive power to the grid for voltage support.

Batteries can be used for distribution system support to maintain reliability and defer investments in new power lines and substations, voltage regulation, as a form of spinning reserve, for generating unit "black start,"[41] and to provide power to a local area in the event of a blackout. A CAES plant can be used for price arbitrage, load leveling, and voltage regulation. Other examples can be added. However, to monetize these services the highly regulated electric market must have

[37] See for example the discussion in Elisabeth A. Gilmore, et al., *The Air Quality And Human Health Effects Of Integrating Utility-Scale Batteries Into The New York State Electricity Grid*, Carnegie Mellon Electricity Industry Center Working Paper CEIC-09-04, 2009, http://wpweb2.tepper.cmu.edu/ceic/papers/ceic-09-04.asp.

[38] For additional information on power plant costs see CRS Report RL34746, *Power Plants: Characteristics and Costs*, by (name redacted).

[39] Telephone conversation with Dan Rastler, EPRI, August 27, 2009.

[40] Dr. Robert B. Schainker, EPRI, "Emerging Technologies to Increase Penetration and Availability of Renewables: Energy Storage – Executive Summary," presentation, California Energy Commission Integrated Energy Policy Workshop, July 31, 2008, slide 3, http://www.swsolartech.com/pdf/EPRI-July2008Report.pdf.

[41] In the event of a blackout, generating units that have shut down need an outside source of power to restart. These emergency generators are referred to as black start units. Examples are diesel generators and some types of combustion turbines. Storage units might also serve this role.

rates and payment arrangements that account for the benefits from EPS. As discussed below, this regulatory framework is still evolving.

Regulatory Issues

This section begins with a background review of electric power regulation in the United States, and then discusses regulatory issues as they pertain to electric power storage.[42]

Regulatory Background

The regulation of electric power in the United States is a patchwork quilt of federal and state authorities. The most important distinction to make is between traditional and restructured state markets. As explained by DOE, in the many states that continue to operate traditional markets, many investor-owned utilities (IOUs), municipal, and cooperative utilities:

> still provide electric service under a traditional vertically integrated business model, owning and operating generation, transmission, and distribution facilities and measures while selling "bundled" retail service to their end-use consumers. These utilities provide retail service under a "cost-of-service" model; thus, their rates reflect their costs of providing service plus a reasonable return (or in the case of not-for-profit co-ops and public power systems, a financial reserve).[43]

In these traditional markets, allowable costs, retail rates, and operating practices are monitored and controlled by a state public utility commission. New investments, such as in power plants, power lines, or EPS facilities, must be approved by the state commission. Traditional regulation continues to be predominant in the Southeast, Northwest, and other western states outside of California.

Beginning in the 1990s, restructured markets developed in many states in the Northeast, New England, much of the Midwest, Texas, and California.[44] For the most part these were areas with high electric prices where the state governments concluded that introducing more competition into the power markets could drive down rates and improve service.

There is no standard form of restructured market, but some typical elements include:

- Vertically integrated utilities sold their power plants to independent power producers. The utilities are now "wires" companies that buy power wholesale from the generating companies.

[42] A full discussion of the competitive restructuring of the electric power market is beyond the scope of this report. For summaries of these developments, see The Electricity Advisory Committee, *Keeping the Lights on in a New World*, U.S. Department of Energy, Washington, DC, January 2009, sections 1.7 to 1.10, http://www.oe.energy.gov/eac.htm; and Federal Energy Regulatory Commission, Order No. 890, Final Rule, issued February 16, 2007, pp. 6-21, http://www.ferc.gov/legal/maj-ord-reg.asp.

[43] DOE, Electric Advisory Committee, Keeping the Lights on in a New World, January 2009, p. 20, http://www.oe.energy.gov/DocumentsandMedia/adequacy_report_01-09-09.pdf.

[44] The American Public Power Association (APPA) website maintains state-by-state information on power market regulation; see http://www.appanet.org/aboutpublic/staterestructurlist.cfm.

- Wholesale electricity prices not covered by contracts are set daily or hourly by a bidding process managed by a centralized market maker, the regional transmission organization (RTO).
- The RTO also establishes market rules and tariffs generally, including tariffs for setting the prices of "ancillary services" such as voltage regulation and spinning reserve. RTOs also take over operation of the transmission network in a region or large state, although utilities continue to own their systems, and set rules for how the grid is managed. [45]

In the restructured markets, state commissions continue to set the framework for retail rates. But since these rates must reflect, at least over the long term, the wholesale cost of power, consumers are more exposed to market fluctuations than in traditional states. Additionally, because RTO markets set wholesale prices based on the marginal—that is, highest cost—bid, consumers in restructured states pay rates that reflect these marginal prices rather than the retail rates based on average costs that are set by commissions in traditional markets.

Both the traditional and restructured markets are subject, in important respects, to federal regulation. Wholesale electricity rates and transmission rates are under the aegis of FERC. Although FERC has moved over the years from cost-of-service regulation to encouraging market-based rates, the operation of these markets, if not individual rates and prices, remains tightly regulated. All tariffs for market-based rates, other rules and regulations of RTOs, and generally any activity by RTOs and jurisdictional utilities that impact operation of the interstate power markets require FERC approval.[46]

Power Market Regulation and Electric Power Storage

Restructured and traditional power markets pose different challenges to EPS projects. Restructured markets by design expose and put a price on the multiple services that compose the power market, including the ancillary services that storage can provide, such as regulation and spinning reserve. This can allow storage projects, which can be expensive, to exploit multiple revenue streams. The constantly changing market prices in restructured markets also provide additional opportunities to use EPS for price arbitrage. Countering these advantages, restructured markets operate using complex rules that have probably not been designed to accommodate the specific characteristics of electricity storage, such as the ability of a single facility to serve transmission and generation functions or the short discharge duration of some storage technologies.

[45] RTOs also ensure open access to the grid, coordinate transmission planning, establish mechanisms to pay for new transmission lines. and in some cases operate capacity markets which arrange for new power plants to be built. Similar in function to RTOs are independent system operators (ISOs) and the terms are sometimes used interchangeably. However, the only ISOs to be qualified as RTOs under the terms of FERC's Order 2000 are ISO-New England, PJM, the Midwest ISO, and the SPP RTO.

[46] This said, the scope of FERC's authority is primarily limited to IOUs located outside of Texas, Alaska, and Hawaii. FERC does not have economic regulatory authority over public power entities, most cooperatives, and most of Texas. (Most of Texas is covered by the ERCOT RTO. The entities which eventually formed ERCOT severed non-emergency connections with outside grids in August 1935, when the Federal Power Act became effective, in order to avoid falling under the ratemaking jurisdiction of the Federal Power Commission (FERC's predecessor) by maintaining a purely intrastate system.) The primary exception to these limitations is FERC's authority over the reliability of the bulk power system, which covers the entire contiguous United States.

An example of the regulatory complications that can ensnare EPS projects is the Lake Elsinore Advanced Pumped Storage (LEAPS) project, a rare case of a proposed new HPS facility. In 2006 FERC designated LEAPS as an advanced transmission technology, but the California ISO (CAISO, the organization that runs the power market in most of the state) concluded it should be treated as a generating unit. This ruling was eventually upheld by FERC, "effectively leaving [the] storage [project] in a state of limbo."[47]

It may seem odd that an HPS project, using the one storage technology with a long track record, should fall between the cracks in the regulatory system. However, HPS projects were for the most part constructed years ago in a different and much simpler regulatory environment, and although the technology has been used for decades the handful of HPS facilities has not produced an extensive or definitive set of regulatory precedents.[48] The quandary is summarized by one analysis:

> Transmission owners with assets managed by independent system operators (ISO) can't put storage assets in their [regulated] rate base, because those assets also provide [deregulated] generation services. Similarly, distribution utilities frequently can't justify the cost of energy storage only on the basis of its distribution-system benefits. And generation companies struggle to make energy storage pay off, because the market hasn't yet developed bilateral contracts that value the full range of energy storage services.[49]

In 2008 and 2009, RTOs began to change their rules, procedures, and operating software systems to account for electricity storage. ISO New England, the New York ISO, and the Midwest ISO (MISO) have all adopted temporary or permanent rules changes to facilitate the use of EPS for regulation services.[50] However, these changes do not address other storage services or the potential contribution of large-scale storage projects. For example, one power company has asked FERC to require MISO to begin discussing "with stakeholders potential modifications to its Tariff or business practices to allow the incorporation of the long-term storage technologies."[51] In a development that may prove significant, a FERC commissioner stated in July 2009 that the agency is exploring whether to adopt a national EPS pricing policy that would address such issues as the ability of storage devices to act as both generation and transmission facilities.[52]

Traditional markets, where rates for vertically integrated utilities are set for a bundle of services by state utility commissions, present a simpler but still problematic environment for storage projects. Because in these markets separate prices are often not exposed for individual services,

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[47] Michael T. Burr, "Storage Goes Mainstream," *Public Utilities Fortnightly*, April 2009, p. 28. This project is also dealing with other legal and financial challenges; see the grand jury report and reply at http://www.evmwd.com/depts/admin/public_affairs/leaps/informational_materials.asp.

[48] Electricity Advisory Committee, DOE, *Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid*, December 2008, p. 15, http://www.oe.energy.gov/DocumentsandMedia/final-energy-storage_12-16-08.pdf.

[49] Michael T. Burr, "Storage Goes Mainstream," *Public Utilities Fortnightly*, April 2009, p. 27.

[50] Craig Cano, "ISO-NE Can Conduct Pilot To Get Regulation Services From New, Alternative Technologies," *Platts Inside FERC*, September 22, 2008; Lisa Lawson, "NYISO Seeks Tariff Revisions to Integrate Energy Storage Technologies into Market," *Platts Inside FERC*, March 23, 2009; Craig Cano, "MISO Files Further Revisions to Make Better Use of Stored Energy Resources," *Platts Inside FERC*, May 18, 2009;

[51] Motion to Intervene and Comments of Xcel Energy Services Inc., Before the Federal Energy Regulatory Commission, Docket No. ER09-1126-000, June 2, 2009, p. 16 (available through FERC docket search at http://elibrary.ferc.gov/idmws/docket_search.asp).

[52] "FERC Examining First-Ever Comprehensive Storage Pricing Policy," *Energy Washington Week*, July 29, 2009.

such as spinning reserve, it can be difficult to decide how to value a storage project. EPS may also compare unfavorably with alternative technologies with more cost and technical certainty. For example, quick-start combustion turbines are a mature technology that can be used for spinning reserve, regulation, and black start. They do not have other capabilities that storage can provide, such as price arbitrage, but this may be outweighed in the eyes of utility commissions by the fact they are known commodities. One utility executive said that:

> "if the cost of that [electricity storage] solution for now is 30% higher than a traditional solution, then you've got to have a willingness on the part of regulators or governmental agencies to either go ahead and put things in rate base that are a little more expensive for now, knowing that what we're doing is incubating a new technology." Alternatively, incentives must be found "that enable you to make up that cost differential—in the case of storage it seems like it's coming up around 30%."[53]

On the other hand, utility commissioners may be reluctant to spend ratepayer money on what they view as technological experiments. Another consideration are the economic incentives utilities face in traditional markets. In these markets the allowed rate of return is in part a function of the size of the utility's "rate base"—that is, the amount of capital invested in plant and equipment. Other things being equal, the larger a utility company's capital investments the more money it will be allowed to earn in rates. This incentive can make public utility commissions skeptical of utility plans to invest in expensive new technologies.

Transmission Planning as an Institutional Issue

Many analysts have identified a need to expand the national transmission system. The objectives of system expansion include renewable energy development, transmission line congestion relief, and reliability improvement. [54] Proposals for how to plan and implement transmission grid expansion can be categorized as follows:

- *National transmission "interstate highway" system*. This concept envisions multi-billion-dollar development of a new network of high-voltage transmission lines spanning the continent. Planning has not proceeded past general concepts.[55]
- *Major interregional projects*. These projects involve long-distance, interregional transmission construction, though not at the scale of the national system discussed above.[56]
- *Regional development*. This concept would rely on local and nearby renewable resources rather than distant resources. An example is serving Northeastern

[53] Larry Dickerman, director of AEP's distribution engineering services, quoted in Paul Ciampoli, "AEP Executive Urges Attention To Systemic Benefits, 'Game Changing' Potential Of Storage" *Platts Electric Utility Week*, February 23, 2009.

[54] For additional information see CRS Report R40511, *Electric Power Transmission: Background and Policy Issues*, by (name redacted).

[55] For alternative views of this concept see Bracken Hendricks, Center for American Progress, *Wired for Progress: Building a National Clean-Energy Smart Grid*, February 2009, http://www.americanprogress.org/issues/2009/02/pdf/electricity_grid.pdf; and Kevin Bullis, "A Costly and Unnecessary New Electricity Grid," Technology Review, July 14, 2009, http://www.technologyreview.com/energy/22997/.

[56] An example is the Joint Coordinated System Plan proposal for developing a new network of transmission lines to move wind power from the Midwest to the Northeast and Southeast; see http://www.jcspstudy.org/.

demand for renewable power with PV generation, off-shore wind farms, and hydroelectric power imports from Quebec.

- *Integrated Solutions.* This approach aims to give full attention to non-transmission and non-generation alternatives, in addition to large-scale transmission projects. These alternatives include small-scale transmission projects, local renewable resources, demand response and energy efficiency, and EPS. Although this is the most comprehensive planning approach, it also makes transmission planning into something much more akin to development of a complete electric system plan for a region. Integrated planning implies involvement of a large range of stakeholders, complex analyses, consideration of long-term economic objectives, and perhaps a time-consuming process.

Electricity storage potentially fits into all of these approaches to transmission planning, but in perhaps different ways. For example, large centralized storage facilities might play a role in national or regional transmission projects intended to bring large amounts of wind power from the northern plains to cities; distributed storage could be used in the regional planning approaches. But one question is to what extent will EPS be considered at all.

These varying approaches to transmission planning reflect major divides in views of the future of the power system. One divide is between those who believe that major, long-distance transmission development is unavoidable, largely to access new sources of renewable power, and the alternative view that local resource development can obviate much of the need for new transmission lines. A second, perhaps even more fundamental divide, is between traditional utility approaches to resolving power systems issues—which focus on central station power plants and large transmission projects—and new approaches which rely on diverse resources. EPS is an example of an alternative resource that does not fit easily into the traditional utility paradigm. This is in part because many storage technologies are distributed rather than centralized, and in part because single storage technologies can serve multiple purposes—it is a peg that fits into several holes, round and square, of different sizes.

Which transmission planning approach—or approaches—are ultimately adopted will be the result of policy decisions informed by many technical, cost, and political considerations. The degree to which EPS plays a role in these planning decisions and planning processes may be influenced in part by federal policy, as discussed in the next section of the report.

Issues for Congressional Consideration

As noted above, EPS faces regulatory, economic, and institutional barriers to widespread acceptance. This concluding section of the report discusses oversight and legislative approaches to addressing these barriers that may be of interest to Congress.

Industry and Regulator Acceptance of Storage

Electricity storage is one of several technologies and methods of meeting power demand that are of current congressional interest (including distributed generation, renewable power, and demand

response[57]) which do not fit the traditional power industry paradigm. That paradigm involves reliance on large-scale central power plants and long-distance transmission lines to meet demand. As noted above, this raises the question of how quickly and effectively the power industry and its federal and state regulators will be willing to pursue and deploy new approaches that are cost-effective. [58] A DOE study sums up the adoption issue:

> A utility that is guaranteed [by regulators] 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.[59]

As discussed above, efforts are underway at the state and federal level to address the regulatory issues. But because utility regulation is decentralized in the United States, this is likely to be a lengthy process that Congress may want to monitor.

Executive Agency Focus

Another possible issue for congressional oversight is whether executive agencies are taking appropriate cognizance of EPS in studies and actions. This is part of the larger issue of whether executive agencies, like their counterparts in industry and the states, are considering the full range of non-traditional solutions (when they are cost-effective) to power systems needs.

Two recent studies of electric power issues, one by DOE and another by FERC, illustrate potential oversight issues. In 2008 DOE published *20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply*, a major study that "examines some of the costs, challenges, and key impacts of generating 20% of the nation's electricity from wind energy in 2030."[60] A major issue in integrating large amounts of wind capacity into the power system is the variability of wind power. Large-scale wind integration requires steps to compensate for the times when wind power is either reduced or unavailable due to weather conditions. To date this has not

[57] Demand response involves creating incentives or controls that cause the demand for power to change in response to power prices and/or availability. It reverses the historical method of operating a power system, in which power plant output response to changes in demand. Demand response in the industrial and commercial sectors in a growing resource available to grid operators in some parts of the country, and the smart grid is seen as the technological component that may be necessary to bring demand response to the residential sector. The issue is complex and somewhat controversial when proposed demand response programs involve changes to utility economic incentives and residential rates.

[58] While utilities and their regulators are sometimes described as technically conservative organizations, the level of conservatism seems, at least in some cases, to have more to do with how far a new approach varies from traditional operating practices than how new the technology is. An example is how readily much of the power industry and its regulators adopted nuclear power in the 1960s and 1970s. The technology fit the central station paradigm, but it was largely untested and proved to be vastly more expensive and operationally challenging than expected.

[59] Electricity Advisory Committee, DOE, *Bottling Electricity: Storage as a Strategic Tool for Managing Variability and Capacity Concerns in the Modern Grid*, December 2008, p. 16, http://www.oe.energy.gov/DocumentsandMedia/final-energy-storage_12-16-08.pdf.

[60] DOE, 20% Wind Energy by 2030: Increasing Wind Energy's Contribution to U.S. Electricity Supply, July 2008, p.2, http://www1.eere.energy.gov/windandhydro/pdfs/41869.pdf.

been a major issue because few areas have sufficient wind power to create integration issues, but this is expected to change in the future.

The conventional approach to wind integration is to install quick-start natural gas-fired combustion turbine power plants to back up wind power. Other options that have been proposed include geographic dispersion of wind farms, improved wind power forecasting techniques, implementation of demand response and smart grid technologies and procedures, aggregation of utility control areas, and EPS. However, DOE's study essentially disregards the EPS option.[61]

There is no unanimity of opinion on the extent to which EPS will be needed, if at all, to integrate large amounts of wind and other renewable power capacity into the grid. The American Wind Association, for example, believes that electricity storage is too costly and is unnecessary for wind integration.[62] However, this opinion is not universally held. For example, a recent North American Electric Reliability Corp. (NERC)[63] study of renewable integration concluded that "Additional flexible resources, such as demand response, plug-in hybrid electric vehicles, and storage capacity, e.g., compressed air energy storage (CAES), may help to balance the steep ramps associated with variable generation."[64] A white paper issued by the American Society of Chemical Engineers concluded that large-scale electricity storage "is the critical technology needed by renewable power if it is to become a major source of baseload dispatchable power to eventually replace fossil/nuclear plants."[65] The chief of the PJM Interconnection, the operator of the power grid in much of the Middle Atlantic and Midwest, believes that 1,000 MW or more of CAES will be needed on the PJM system to support growing wind capacity, and two utilities in California have recently announced proposed CAES and battery projects to facilitate wind power integration.[66] With this diversity of opinions, it is unclear why the DOE study would not take more cognizance of options like EPS and demand response as part of the suite of tools available to integrate wind into the power system.

Another example of a perhaps narrow agency focus is a recent FERC study, *A National Assessment of Demand Response Potential*.[67] In response to a mandate included in the Energy

[61] The DOE study's brief discussion of storage is on pages 80 and 81. The modeling performed for the study could incorporate only storage located at a wind plant site, by some estimates an inefficient and expensive approach (Jeff Anthony, American Wind Energy Association, "Wind Energy & Energy Storage," *Platts Power Storage Conference*, Las Vegas, NV, June 15, 2009, slide 29; Jonathan Fahey, "Hold that Electron!," *Forbes*, November 24, 2008), and it is not clear if this option was actually implemented in the model runs (see the DOE report, page 191). Demand response is not mentioned in the DOE report and the smart grid is discussed only in passing.

[62] Jeff Anthony, American Wind Energy Association, "Wind Energy & Energy Storage," *Platts Power Storage Conference*, Las Vegas, NV, June 15, 2009, slide 38. For a similar perspective see National Academies, *Electricity From Renewable Resources*, prepublication copy, 2009, pp. 78, 79, and 84. On the notion that wind power may be more suitable for storage than solar power see http://energyoutlook.blogspot.com/2009/03/storing-sunlight.html.

[63] NERC is an industry association that has been designated by FERC as the official electric reliability organization for the United States.

[64] NERC, *Accommodating High Levels of Variable Generation*, April 2009, p. iii, http://web.ta-alberta.ca/downloads/IVGTF_Report_041609(1).pdf.

[65] Bernard Lee and (name redacted), American Institute of Chemical Engineers White Paper, *Massive Electricity Storage*, June 2008, pp. 2-3, http://www.aiche.org/uploadedFiles/About/DepartmentUploads/PDFs/MES%20White%20Paper%20submittal%20to%20GRC%206-2008.pdf.

[66] Jeff Ryser, "Electricity Storage Technology Moves Forward with Support by Grid Operators," *Platts Electric Utility Week*, April 6, 2009; Tracy Seipel, "PG&E to Build Plant to Store Wind Energy," *San Jose Mercury News*, August 27, 2009; Poornima Gupta, "Utility Wants To Deploy Largest Grid Battery Ever," Reuters, August 26, 2009, http://www.reuters.com/article/GCA-GreenBusiness/idUSTRE57P4PJ20090826.

[67] FERC, *A National Assessment of Demand Response Potential*, June 2009, http://www.ferc.gov/legal/staff-reports/06-(continued...)

Independence and Security Act of 2007,[68] the report assesses the demand response potential, state by state, for the period 2010 through 2019. The estimates are made for several scenarios which incorporate varying levels of technological advancements and changes to rate structures, including:

- Dynamic rates, in which the rates charged for electricity vary daily or in real time to reflect wholesale power prices and scarcity in electricity supplies. This is a substantial departure from the average price rates typically charged to residential customers.
- Dynamic rates combined with "enabling technologies" that automatically respond to high power prices by reducing a home's electricity demand.
- Direct load control of consumer equipment, such as air conditioners, by the utility.
- Interruptible tariffs, in which large industrial and commercial customers agree to reduce demand under certain conditions in return for a financial incentive.
- Other programs aimed at reducing demand as needed from large industrial and commercial customers.

Some of these approaches to demand response are currently routine or can be easily implemented, such as interruptible tariffs and direct load control. Dynamic rates, as noted, would represent a substantial change for residential customers and have been controversial.[69] The enabling technologies that can augment dynamic rates have been pilot tested at a residential scale but not widely deployed. Depending on the scenario, the study assumes up to universal installation of smart meters, 60% to 70% customer participation in dynamic pricing, and 60% of customers using enabling technologies.[70]

A potential oversight issue is whether FERC has been unnecessarily restrictive in the choice of technologies and options it examined for reducing and shifting peak demands (a central goal of demand response programs). The report states that:

> Other examples [of currently high-cost options] include battery storage and thermal energy storage. Both items hold the potential to significantly reduce peak demand on a permanent basis by shifting it to off-peak periods. As in the case of photovoltaic arrays, cost is a significant barrier to their rapid market penetration today. Another example is behind-the-meter generation which includes a diverse set of technologies including small conventional generation units that are used as back-up generation during emergencies and cogeneration systems that combine heat and power, largely in industrial process applications.[71]

(...continued)

09-demand-response.pdf.

[68] P.L. 110-140, section 529.

[69] Tom Tiernan, "Utilities Sometimes in the Middle as Enthusiasm, Wariness Circle Each Other in Smart Grid Push," *Platts Electric Utility Week*, November 3, 2008.

[70] An additional scenario assumes, for example, mandatory dynamic pricing for all customers, but this scenario is used simply to determine the hypothetical upper limit of energy savings from demand response.

[71] FERC, *A National Assessment of Demand Response Potential*, June 2009, p. 48, http://www.ferc.gov/legal/staff-reports/06-09-demand-response.pdf.

It is not clear why universal roll-out of smart meters (itself a multi-billion-dollar expense), widespread deployment of thermostats that respond to power prices, or large-scale implementation of dynamic pricing (a ratemaking approach currently almost unknown in the residential sector) would be more likely than deployment of EPS systems by 2019. Also unclear is the treatment of distributed generation—which in the industrial and commercial sectors has been used routinely for decades[72]—as a developmental option.

FERC perhaps had to limit the range of options it could consider in its demand response report, but this study and the DOE wind report also reflect the risks of not giving fuller attention to the full range of options available to meet power system needs. As discussed below, two major pieces of proposed legislation before the 111th Congress both treat EPS as a demand response option for managing peak loads. To the degree that Congress is interested in the advancement of EPS technology, it may want to monitor how this option is being considered in agency studies and programs.

Current Legislation and Incentives

This section of the report reviews the treatment of electric power storage in three current legislative proposals:

- S. 1091, the Storage Technology of Renewable and Green Energy Act of 2009 (STORAGE Act).
- H.R. 2454, the American Clean Energy and Security Act of 2009 (ACES).
- S. 1462, the American Clean Energy Leadership Act of 2009 (ACELA).

This section also summarizes the financial incentives available to EPS projects in the American Recovery and Reinvestment Act of 2009 (ARRA; P.L. 111-5).

STORAGE Act

The STORAGE Act would amend the tax code to create incentives for EPS deployment. These incentives include:

- A 20% business investment tax credit for investments in EPS systems that deliver stored power for sale, and have a minimum output capacity of 0.5 MW during a four-hour delivery period.
- A 20% business investment tax credit for investments in EPS systems located at the consumer site, and used primarily to store and deliver renewable energy generated onsite that is used to reduce onsite peak power demand. These can be small systems: the minimum required output is five kilowatts during a four-hour delivery period.

[72] The predominant form of distributed generation is combined heat and power, also referred to as cogeneration. For more information see Oak Ridge National Laboratory, *Combined Heat and Power: Effective Energy Solutions for a Sustainable Future*, December 1, 2008, http://www1.eere.energy.gov/industry/distributedenergy/.

- A 30% residential tax credit for an EPS system installed in a home, and used primarily to store and deliver renewable energy generated onsite that is used to reduce onsite peak power demand. No minimum size requirements are specified.
- The bill would allow government and cooperative power agencies to issue Clean Renewable Energy Bonds[73] for storage projects.

The STORAGE Act was introduced on May 20, 2009, and referred to the Finance Committee. As of late August 2009 no further action had been taken on the bill.

ACES and ACELA

ACES is a climate change and energy policy act passed by the House on June 26, 2009, and referred to the Senate.[74] Many of the objectives of the bill, including increased use of renewable power, peak demand reductions, and reductions in carbon emissions, might be facilitated by cost-effective EPS. With respect to transmission planning, the bill would establish a national transmission planning policy that takes:

> into account all significant demand-side and supply-side options, including energy efficiency, distributed generation, renewable energy and zero-carbon electricity generation technologies, smart-grid technologies and practices, demand response, electricity storage, voltage regulation technologies, high capacity conductors … superconductor technologies, underground transmission technologies, and new conventional electric transmission capacity and corridors.[75]

The bill's peak demand reduction section also specifies EPS as one of the technologies that can be used to meet reduction goals.[76]

ACELA is an energy bill that was introduced on July 16, 2009, when it was reported out of the Senate Energy Committee. The bill includes a peak reduction and load shifting goal that would be met through the "widespread implementation" of several demand response technologies, including dynamic pricing, smart grid technology, distributed generation, and electricity storage.[77] The bill would also establish a multi-faceted national transmission policy. The first principle listed is "support for the development of new renewable energy generation capacity," but there are numerous other objectives, including cost savings, reliability enhancement, reduced power plant emissions, and maximizing "the contribution of demand side management (including energy efficiency and demand response), energy storage, distributed generation resources, and smart grid investments." Transmission planning would be required to reflect these policy objectives.[78]

Both ACES and ACELA therefore anticipate transmission planning processes that would take the integrated approach discussed earlier in this report. Both bills also include electricity storage

[73] For more information on this bond program see http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US45F&re=1&ee=1.

[74] For more information on ACES see CRS Report R40643, *Greenhouse Gas Legislation: Summary and Analysis of H.R. 2454 as Passed by the House of Representatives*, coordinated by (name redacted) and (name redacted).

[75] H.R. 2454, Title I, Subtitle F, section 151.

[76] H.R. 2454, Title I, Subtitle D, section 295.

[77] S. 1462, Title II, Subtitle D, section 295.

[78] S. 1462, Title I, Subtitle B, section 121.

among the demand response technologies that can be used to meet goals for reducing peak demand. If either bill becomes law, Congress may want to monitor whether storage and other non-traditional approaches actually receive appropriate attention from industry, regulators, and executive agencies.

The American Recovery and Reinvestment Act of 2009 (ARRA; P.L. 111-5) added or expanded funding and incentives for electricity storage. [79] However, many of the programs seem to be focused primarily on one application, battery technology for pure electric and plug-in hybrid electric vehicles.[80]

- ARRA provides $6.0 billion that is expected to leverage more than $60 billion in federal loan guarantees for transmission grid construction that supports renewable energy projects. These guarantees can presumably be used to support applicable EPS projects. This new loan guarantee program expands the existing innovative technology loan guarantee program created by the Energy Policy Act of 2005 (EPACT05).[81] Although the EPACT05 program is limited to supporting "pre-commercial" innovative technology, the new program can also support commercial technology. Qualifying projects must be capable of starting construction no later than September 30, 2011.
- ARRA provides $300 million for a Department of Defense "Near Term Energy Efficiency Technology Demonstrations and Research" program. According to the conference committee report, electricity storage is one of the applications to which this money can be applied.[82]
- The act provides $4.5 billion to DOE's Office of Electricity Delivery and Energy Reliability for grid modernization and related technologies, such as electricity storage.[83]
- The law establishes a tax credit that can be used to re-equip, expand, or establish a facility that is designed to manufacture equipment that is used to produce, for example, electricity storage systems for electric/hybrid vehicles, renewable energy systems, fuel cells, and other specified technologies. The law allows for up to $2.3 billion in credits. [84]
- ARRA establishes a new program of $2.0 billion for facility funding grants to manufacturers of advanced battery and battery system components. Covered activities include the production of lithium ion batteries, hybrid electrical systems, system components, and software.[85]

[79] For additional information see CRS Report R40412, *Energy Provisions in the American Recovery and Reinvestment Act of 2009 (P.L. 111-5)*, coordinated by (name redacted).

[80] On August 5, 2009, President Obama announced $2.4 billion in ARRA grants to "accelerate the development of U.S. manufacturing capacity for batteries and electric drive components as well as the deployment of electric drive vehicles." For more information see the DOE press release at http://www.energy.gov/news2009/7749.htm.

[81] For further information on the loan guarantee program see 42 USC §16511 et seq and the DOE website at http://www.lgprogram.energy.gov/. The $6 billion in funding would be directed to renewables and transmission by a new section 1705 added to EPACT05.

[82] P.L. 111-5, Division A, Title III; and H.Rept. 111-16, pp. 422-423.

[83] P.L. 111-5, Division A, Title IV.

[84] P.L. 111-5, Division B, Title I, Subtitle D, section 1302.

[85] P.L. 111-5, Division A, Title IV.

- ARRA modifies an existing tax credit for the purchase of new plug-in vehicles (plug-in hybrids and pure electric vehicles) to cap the per-vehicle credit at $7,500 for light-duty vehicles and heavy-duty vehicles up to 14,000 pounds gross weight. [86]
- The law adds $2.4 billion to an existing $800 million Energy Conservation Bond program. The bonds can be applied to many purposes, including advanced automobile batteries and advanced battery manufacturing technology. [87]

To the extent that Congress is interested in widespread adoption of cost effective EPS technologies, it may want to oversee the extent to which these incentives are committed to electricity storage devices other than vehicle battery systems.

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[86] P.L. 111-5, Division B, Title I, Subtitle B.

[87] P.L. 111-5, Division B, Title I, Subtitle B.