DRAFT “Energy Advisory Committee” – Energy Storage Subcommittee Report

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1. Introduction

Energy storage plays a vital role in all forms of business and affects the daily life of virtually every citizen in the US. The rapid advancement of communications and information processing technologies are a good example of an industry built on small amounts of energy storage in hand-held devices being the critical platform for reliable performance of a major sector of everyday life. Now the same information and communications technologies will be the primary drivers in transforming the US electrical grid into a more reliable, more secure and more efficient network capable of dealing with massive changes over the next two decades. In supporting this growth and smart grid capabilities; what types, and how much, energy storage will be needed to facilitate this process.

The purpose of this report is to provide guidance to the DOE with respect to establishment of a roadmap for energy storage in the US grid and the anticipated impact to plug-in electrical vehicles. The report addresses recommendations for a five-year plan to help insure that the US maintains a leadership position with regard to energy storage competitiveness and manufacturing.

1.1 Background

The first application of large-scale energy storage (31 MW) in the US occurred in 1929 when the first pumped hydro electric plant was placed into service. Pumping water from a lower elevation to a higher elevation was the most practical way to store large amounts of energy that can then be released during periods of high, or peak, demand. These plants can be used to help manage grid frequency and provide clean reserve generation known as ancillary services. During a 30-year period from the late 1950s to the late 1980s when most of the nation's nuclear power stations were brought into service, approximately 19,500 megawatts of pumped hydro storage facilities were brought into service in the US. By 2000 about 2.5% of the total power delivered in the nation's grid was supplied through these storage facilities. Because of the need for significant elevation changes in pumped hydro plan designs, the number of environmentally-acceptable sites for future pumped hydro facilities is very limited. Siting of new plants would meet the same objections that siting new transmission lines face today. Nevertheless, planning is underway to add new pumped hydro plants to the US grid.

Currently the technology receiving the most attention for use in large-scale storage is compressed air energy storage (CAES). A 115 MW CAES demonstration plant was placed in service in the early 1990s and has proven to be effective. Underground formations such as salt domes and depleted gas fields can be adapted for use with CAES technology. These systems appear to be practical in a power range above 100 MWs up to several thousand megawatts. The Electric Power Research Institute (EPRI) has proposed two pilot plants to member utilities. One municipal utility plant is under development in Iowa plus other proposals by commercial developers.

The most common form of energy storage in use today is based on lead acid batteries. The rapid growth of the information age has spawned the construction of data centers to support the internet and communications. All of these facilities are sensitive to utility power quality so large amounts of battery-powered protection systems have been and will continue to be deployed. Powering these types of loads now accounts for over 1.5% of the total utility power consumption in the US.

Total consumption of lead-acid batteries for commercial, industrial and automotive use in the US is currently $2.9B per year and is growing at an annual rate of eight percent per year. In the past use of lead-acid batteries for utility applications like peak shaving were tested but the economics and life-cycle characteristics were not ideal for the daily cycling capabilities desired in utility applications. By contrast lithium-ion battery use is growing rapidly. Potential use of lithium batteries for high power transportation applications have helped drive sales in the US to $1.0B in 2007 with future growth rates projected at 50-60% per year. The ability of lithium ion batteries to economically serve in electric utility applications has not yet been demonstrated except for some ancillary services provision to ISOs.

There are several other electrochemical technologies in use for back-up power applications which are also being investigated or deployed for utility scale applications. These include sodium sulfur, zinc-bromine, vanadium redox, polysulfide-bromine redox, among others. Sodium sulfur is a technology widely used in Japanese utilities and is being deployed in the US today. Zinc-bromine is already commercially successful in the US. The familiar Ni-Cad and Ni-Metal Hydride batteries common to power tools have also found applications in backup power applications but have been surpassed by other technologies for cost and energy density reasons in utility applications.

Additionally, there are other storage technologies with potential performance and cost advantages: direct air compression via windmills, and underground pumped hydroelectric, for example.

The pressing need for better and better electrical storage for Electric Vehicle applications, plus the potential advantages of storage for utility applications in conjunction with renewable generation resources have provided incentives for R&D and venture funding to drive a number of new technologies coming to market. Even so, the potential for even higher performance (energy density) or lower cost electrotechnologies, based simply on analysis of the periodic table of elements, is very large. There is still a need for and a role for Federal R&D in basic electrochemistry to identify the highest potential new material combinations for storage.

1.2 Distributed vs. Bulk Power Storage

The use of pumped hydro and CAES technology are considered “bulk power” storage systems. New classes of batteries have been developed, which are considered suitable for smaller applications and are referred to as “distributed” storage systems. The two main classes of batteries in this category are “flow batteries” and “high temperature batteries” such as sodium sulfur (NaS) and sodium nickel chloride. Unlike lead-acid batteries, these devices are designed to cycle on a daily basis and have useful operating lives in the 10-20 year range. These systems can be designed for run times up to eight (8) hours per day. The term “distributed” storage comes from the fact that the most practical location for these devices is close to load centers typically in or near utility substations. All of these devices are “scaled” chemistries with no emissions and quite operation.

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

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

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

The one energy storage technology poised for both utility and automotive use in Plug-in Hybrid Electric Vehicles (PHEVs) is lithium-based battery technologies. Lithium-ion batteries dominated the portable electronics market and variations in the chemistries of these are yielding higher power designs with improved cycling capability and lower life. Current projections indicate that PHEVs with these new batteries will be on the roads in the 2010-2011 timeframe. The acceptance of these vehicles and the ensuing rate of adoption by the public will determine the timing of their impact on the overall power demand from the utility grid. Assuming most charging of these vehicles occurs at night, the relative impact over time should be positive with respect to the anticipated growth of wind energy sources. Uncontrolled daytime or early evening charging, by contrast, could pose challenges to system economics and capacity. In general, there are also significant basic infrastructure issues to address when a future of widespread PHEV adoption is considered.

Full integration of these new sources of energy demand coupled with the overall increase in electricity use is a major portion of the challenge facing the designers of our grid of the future. The value of energy storage needs to be closely examined to understand where storage can add value. Examples of the value of storage could include capital deferral, improved reliability through islanding (continuing to power a portion of a grid independently from the utility source), better utilization of generation and working with the variable nature of renewable generation.

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

1.3 How much storage would be beneficial?

Determining the amount and overall value of storage that should be added to the grid begins with examination of the marginal cost of generating electricity. The US electric power industry runs at very low capacity factors – perhaps as low as 40%. This has been acceptable to the industry as generation resources have proven to be more cost effective sources of capacity than energy storage resources. The growth of renewables will likely lead to even lower capacity factors for traditional generation sources.

Many of the drivers for Smart Grid come from ambitions to improve capacity factors by shifting the demand curve – either via incentives or controls. There will be inevitable public resistance to the degree of load shifting (and high real time prices) entailed in the use of demand response. Storage offers another path to help "balance" the system – a means to adapt production to demand while improving capacity factors. As such, it is going to end up politically more acceptable and potentially less disruptive to our economy and society. This should provide a powerful motivation to invest in storage R&D.

Another aspect of storage is the potential capture wind energy that would be curtailed due to a lack of transmission infrastructure. For example, wind curtailment has already become common in Texas because of a lack of transmission capacity to move that power from West Texas to load centers in other parts of the state.

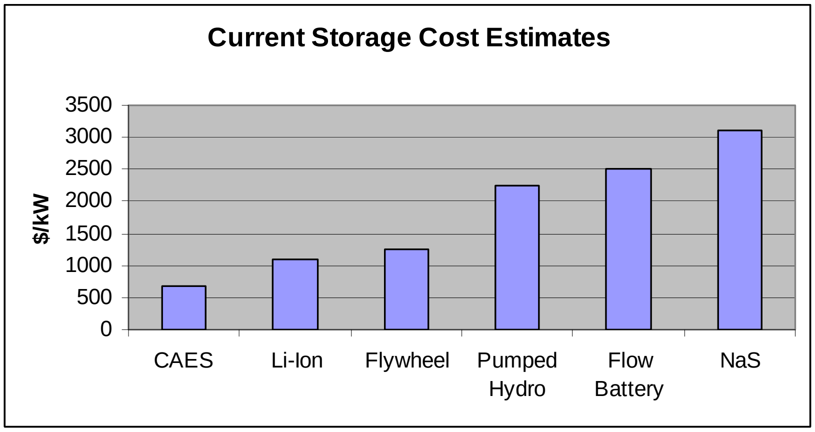
In addition, as wind penetration increases beyond certain levels, wind output may begin to exceed electricity demand during certain hours of the year, which would necessitate curtailment. This problem can be aggravated by inflexible nuclear and coal plants that have limited ability to decrease their output.

The DOE "20% Wind Energy by 2030" report issued in May 2008 defines the scenario to achieve full integration of 300 GWs of wind energy in the US grid. To deal with the variability of the wind resources, approximately 50 GW of new peaking gas turbines would be used to supplement the wind power's output. What portion of this capacity could be economically served by storage? Studies by ERCOT and CALISO indicate that there may be a need for 15 minute Non-Spin market in order to minimize the number of generators needed to be kept spinning as fast back-up.

In looking at the energy storage alternatives, Exhibit 1 shows the current cost estimates for various types of storage technology available today. With the exception of CAES, all other forms of storage have no emissions associated with the energy discharge cycle. CAES systems blend compressed air with natural gas to generate power.

Exhibit 1-1: Energy Storage Cost Estimates

Comment [MW1]: The cost figures for pumped hydro and CAES do not appear to be accurate. The cost figures I have seen quoted for pumped hydro are typically around $1000-$11000/kW (SMUD's Iowa Hill pumped storage plant is expected to cost $1100/kW), while CAES is closer to $1500-2000/kW.



The storage technologies types should be divided into two categories; hours of runtime and minutes. Currently flywheels and lithium-ion batteries are rated for smaller amounts of energy such as frequency regulation. All other technologies can provide "hours" of storage in addition to use in ancillary services like frequency regulation. One of the issues that need attention is development of lower cost storage systems in the 1 to 4 hour range through product improvements in existing technologies or new technologies.

1.4 Objectives of this Report

The goal of this report is to provide recommendations to the DOE on the best path forward to making effective use of energy storage in the US electrical grid, and to prepare the electrical power business to accept connection of large numbers of PHEVs to the grid.

The target benefits of storage in the grid that need attention are:

1. Using storage to improve grid optimization for bulk power production.
2. Storage as an enhancement to variable or diurnal renewable energy sources.
3. Integration of PHEV power demands with the grid.
4. Storage as a way to defer investments in T&D infrastructure to meet peak loads (especially during outage conditions) for a time.

Comment [MW2]: While storage can provide some benefits fro the electric grid that ease the integration of renewables, the full benefits of storage are more fully and properly accounted for by treating it as a system resource as o0ppposed to a resource dedicated to a single generator or type of generator. In addition, the term "variable" more accurately describes the output of renewables like wind than the term "intermittent."

5. Storage as a resource providing ancillary services directly to grid/market operators.

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

The overall report is divided into three major categories:

1. Regulatory issues and potential barriers to adding storage.

2. Growth of storage in PHEVs and the impact on the future smart grid.

3. Meeting the mandates of the Energy Security and Independence Act of 2007.

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

1.5 Applications and Benefits

As stated in the introduction, electricity is the only commodity in the world that, generally speaking, is not normally stored. As a result the fuel (including water behind a dam) used to generate electric power is used as the storage medium, and we have built generation capacity to match peak load – resulting in very low capacity factors for the industry. The shift from fossil fuels to renewable resources as a source of electric power will aggravate this low capacity factor as wind, in particular, often is blowing the hardest at times when electric demand is far from peak. Used to levelize the production / demand mismatch over various time domains, storage has a number of "generation" applications.

One of the most appealing benefits of the Smart Grid in general is that the technologies can be used to shift or control demand to reduce peaks. In order to work, this requires somehow altering consumer behavior. A virtue of storage is that it can accomplish the same supply / demand balancing without imposing behavioral constraints on consumers.

Storage also has potential applications to the transmission and distribution (“T&D”) system because of the ability of modern power electronics and some electro-chemistries to change from full discharge to full charge or vice versa extremely rapidly. These characteristics enable storage to be considered as a means of improving transmission grid reliability.

In between these generation and transmission applications of storage, there is an area wherein storage can be used to alleviate diurnal or other congestion patterns and in effect store energy until the transmission system is capable of delivering it where it is needed.

This application is consistent with recommendation 6, "Pursue Load Balancing Planning" in the FERC Report, "Advanced Transmission Technologies" of May 2008.

At the distribution level, storage can be used in substation applications to improve system power factor and economics, and can be used as a reliability enhancement and a way to defer capital expansion by accommodating peak load conditions.

At the end-use level, storage can be used to capture distributed renewable generation – photovoltaic solar or wind – and store it until it is needed, both for off-grid and grid-connected applications. As such, end-user storage also has the potential to be used to improve grid utilization and reliability, especially if end-user storage can be coordinated with utility operations.

Demand response is increasingly a market resource, including for the provision of ancillary services such as reserves and real time energy, and some DR aggregators additionally want to provide system regulation. Utility scale storage coupled with DR provides the aggregator a higher responsiveness and certainty of response, making DR participation in ancillaries markets more attractive.

A special case of end-user storage is Vehicle to Grid (V2G), whereby Plug-in Hybrid Electric Vehicles with the added capability of discharging back to the grid are used to improve grid utilization, levelize demand, and improve reliability. Because expectations for PHEV deployment are so high, there is great interest in utility circles about the potential for V2G to provide many of the benefits of storage at the distribution and end-user level.

There are also high value niche applications associated with particular end use sectors. An example is the use of storage local to commuter rail stations to provide accelerating power to trains where it is needed and thus minimize losses associated with track catenary distribution. There are other specific industrial applications of this nature which will be developed as MW scale storage technology becomes proven and economic.

In this section we describe the potential benefits of storage across the different infrastructure and time domains with some indications of the performance characteristics required by each application and the estimated economic gains.

1.6 Generation Applications

Exhibit 1-2 Generation Applications summarizes generation domain applications and their benefits. Some general comments are in order:

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

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

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

At a much larger scale, the Dutch government is exploring the creation of an "energy island," whereby a hollowed out artificial island in the North Sea uses pumped hydro in reverse – wind mills operate to pump water out of the island and then hydroelectric turbines generate electricity when it is desired.

Exhibit 1-2: Generation Applications

Definition	Benefit	Benefit as % of system wholesale energy costs	Power Rqmnt (Max)	Duration Rqmnt	Other Reqmnt	Structural Issues	Comments
Generator Autonomous Dynamic Response to Frequency	Renewables Typically Lack Governor Response which is essential for system stability. Increasing conventional unit governor response will cost the markets.		1-5% of associated generation	seconds to a few minutes	sub second response	none; standards for renewable governor response are lacking	This is an unexplored area
Second by second adjustment of power production to match load and schedules and regulate system frequency	Regulation is a defined ancillary service with annual costs to markets on the order of $00Ms. Storage can displace conventional fossil generatio for this purpose and free up generation capacity for energy production. Renewable generation typically lacks	0.2 -0.5%	Typically 1-2% of system peak overall	studies show that 15 - 30 minutes duration required to be effective	rapid (<10 sec) response	in many markets regulation often overlaps short term balancing energy. Control algorithms can be adusted to exploit fast storage response and use storage first for regulation.	Ancillary markets are already a target of merchant storage. Charging losses must be paid in balancing markets so efficiency is a key.
Adjustment of production economically / market based on a minute by minute basis to match demand	In some markets hourly schedule changes cause "spikes" in balancing requirements and prices. Storage used for this purpose would mitigate the spikes. Renewable volatility is expected to greatly increase balancing energy needs which would increase prices	2 - 3%	Balancing is typically 2-3% of system energy today and may double with large renewable penetration.	1 hour or more	Charge efficiencies must be settled in the real time markets so efficiency becomes an important attribute	none; standards for renewable governor response are lacking	another target of merchant storage; short term price arbitraging
Conventional generation provides spinning and operating reserve as back-up against the failure of resources.	Storage can provide short term reserves and enable slower generation to participate; freeing up additional capacity from economic units on line	5%	Spinning reserve is typically matched to the largest unit in a control area or congestion zone; typically 1000 - 1500 MW	15 - 30 minutes if backed up by slower generation	Storage must be kept in a state of charge in order to supply reserves	Unexplored territory except for hydroelectric resources	
Some renewable resources have intra-day behavior (mountain wind locations, ex) which impose scheduling and load matching challenges	Storing renewable production for several hours will utilize more renewable energy and reduce peak fossil production		Depends upon specific resources. Could be range of 30-50% of resource max power capacity	Hours	Energy capacity has to be economic against the value of energy captured	none	
Diurnal Renewable Levelizing	Storing renewable resources from daily peak production for use at peak load hours		Can be as much as 50% of renewable resource production	6 - 12 Hours	ditto	none	
Weekly production levelizing	Store production on weekends for weekday use		can be 20-30 % of peak load for two days	48 hours			typical pumped hydro application
Seasonal production levelizing	store seasonal resources for use in peak load seasons			months			typical hydroelectric function

1.7 Transmission and Distribution Applications

Transmission and Distribution applications are not as far along as generation applications. Also, regulated utilities in general have to be the ones to embrace storage as an approach, and traditionally the T&D sector looks for proven technologies with asset lives of 40 years or more – difficult to demonstrate for many emerging technologies.

One noteworthy leader in applying storage to T&D applications is American Electric Power. AEP is deploying a 5.0Mw NaS battery to solve a transmission issue in South Texas. AEP has stated a commitment to add 1,000Mw's of storage to their grid by 2020.

Power transmission development today becomes a limiting factor in many resource adequacy problems. Transmission capacity to bring remote generation to load centers is limited. Increasingly, new generation has to be sited far from population centers such that the transmission grid is strained. This particular issue has been a rising concern due to the rapid increase of renewable generation implementation. Wind generation in particular has to be built where the wind blows, and typically is in remote / rural or semi-wilderness locations requiring new transmission. Because wind resources typically have capacity factors in the range of 25 – 45% transmission capacity utilization is normally less than 50% of the peak power capacity of the renewable resource. For some wind projects it may make economic sense to build transmission capacity for slightly less than the full nameplate capacity of the project and simply curtail output during the small number of hours per year when output exceeds the available transmission capacity or add storage to control the dispatch of the energy at a different time.

Some wind projects are already experiencing curtailment because of inadequate transmission infrastructure. For example, wind projects in West Texas face negative prices and curtailment during hours of peak output because there is inadequate transmission capacity to move this electricity to other parts of the state. While Texas is moving forward with a $5 billion investment in new transmission capacity to ameliorate this problem, it could take up to 5 years to bring all of this new transmission infrastructure online. Anecdotally, it is reported that in Japan, 30% of the considerable storage installations are associated with renewables in one way or another.

Storage affords the wind farm operator a way to capture power production that would otherwise be curtailed and bank it against a time when the transmission pipe is not loaded to capacity. It also affords the transmission owner / grid operator a chance to defer transmission expansion for a period – transmission capacity is generally not incrementally increased. This is an example of storage providing mutual benefits to generation and transmission.

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

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

A special case of congestion relief is when the limiting transfer capacities are not the physical capacities of the transmission paths in question, but rather are reliability limits arising from post-contingency loading or stability conditions. In the Western U.S., system dynamic and transient stability limits impose restrictions on the North-South power transfers below the physical limits of the transmission lines. In the Northeast, post-contingency voltage conditions similarly limit transfers below the physical capacities.

Very fast storage has the potential, as yet unexplored or validated, to relieve these reliability limitations. In the event of a contingency (sudden unplanned outage of a line or generator) the inverter based storage can theoretically respond in a period of power system cycles (< 0.16 sec) and provide a stability or voltage augmentation. The economic value of relieving these reliability limits is considerable so this is a potential which should be studied.

FACTS devices, which have been heavily promoted as part of the Smart Grid, are based on power electronics. Storage is a natural adjunct to FACTS devices to add capability in special cases.

At the distribution level, storage can provide similar benefits as it does at the generation and transmission level – providing local peak power / time shifting capabilities, grid re-inforcement against peak and against reliability incidents, and providing specialized power electronics-based benefits as well. Providing these benefits with fossil fuel-based generation is usually problematic due to siting and environmental issues, plus distribution applications require completely unmanned operation. Appropriate storage technologies do not suffer from these drawbacks. As an example, while pumped hydro can only be located where suitable dam sites can be created – hardly an urban option; and CAES may be difficult to site in volume in any suburban / urban area; other technologies, particularly dry batteries, lend themselves to distributed deployment in basements and garages. Exhibit 1-3 shows the potential applications of storage in the transmission and distribution systems.

Exhibit 1-3: Transmission Applications

Application	Benefit	Quantification	Power Requirement	Duration	Issues	Comments
Transmission Capacity Factor for Renewables	Capture renewable production and deliver when transmission capacity is available	20-50% of renewable capacity	20-30% of renewable peak production	6-12 hours	uncertain long term economics as capacity is built	Economic issue for wind developers today
Transmission congestion relief	Generalized application of above		Equal to typical congested power on path	hours	ditto	likely to grow in importance
Transmission reliability limit relaxation	specialized technical version of congestion relief relying on very fast storage	$10'sM to $100M+	00s to 1000 MW	seconds to 15 minutes	unexplored and will need bullet-proof analysis and demonstration	would be backed up by quick start reserve in some cases
Transmission capital deferral	relieve short term congestion			hours	very site specific	similar to congestion relief
Substation Peak Load / Backup	defer transformer upgrades (and other upgrades) due to peak load growth	$M per station for 2-5 years deferral	2-10 MW	hours	economics unanalyzed	links to loading issues around DG penetration also
Voltage support						
Reliabiltiy enhancement	provide down-circuit supply while outages restored	???	2-10 MW	hours	economics unanalyzed	alternative to switching alternatives on long rural circuits

While deployment of energy storage on distribution systems can offer all of the benefits available from larger storage units at transmission and generation levels, it would also offer some additional values. One of the highest additional values is deferral of distribution upgrade capital due to the flattening of demand on station transformers and circuits. Also, availability of the stored backup power closer to the end customers at the distribution level would inherently offer a higher service reliability than what could be offered with storage at transmission or generation levels. Due to the nonlinear nature of T&D losses, diurnal peak shaving of energy storage devices would actually reduce T&D losses (IEEE Paper no. TPWRD-00189–2007). The closer the energy storage is located to loads, the higher is the reduction in T&D losses particularly due to the fact that a high percentage of the T&D losses are on the distribution circuits. Another additional value of distribution-level storage, compared to larger units deployed at transmission and generation levels, is the inherent higher security and reliability in storing energy in multiple locations than concentrating them in fewer large centers. The unique distribution system values are significant and should be considered in locating energy storage devices.

1.8 End-User Applications

Storage can be used as an asset for commercial and industrial end-users. For these applications, the device may be utilized as a stand-alone asset or in combination with distributed generation.

For residential end-users, storage can add value as a back-up power device, providing power during outages to provide power to vital appliances. In addition, it can play a role with renewables such as rooftop solar, as a way to store excess renewable production for use when the sun is not shining or the wind not blowing, allowing the resident to avoid using grid energy at those times.

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

This is the very mature UPS market arena that is “booming” now. Total sales this year in the US will be over $3B and growing.

This application has been used by commercial end users with specialized reliability requirements (high value process / production industries). With environmentally and economically attractive storage, possibly economically assisted by price arbitraging and linkages to DR, this may become an increasing application for all commercial end-users.

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

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

Storage also has the ability to benefit current programs such as demand response. Demand response providers, as noted in the first page of this section, increasingly want to participate in ancillary markets. However, doing so can impose burdens on the user affected – demand response as a capacity resource which is used ony a few times a year is very different from the concept of aggregating thousands of household appliances to be demand response which is used hourly and variably, and can also be suspect in terms of responsiveness and certainty. As with distributed generation, storage at the end-user site is a natural complement to demand response applications and has the chance to play a vital role in demand response programs. Renewables, particular residential solar, have the potential to provide demand response capabilities but are currently unable to do so due to their variable nature. By combining storage with renewable distributed generation, the technologies can provide a guaranteed response to a demand response signal, by utilizing either the renewable generation or the storage device that it has charged. Storage serves as an enabling technology for renewable-based demand response.

Ultimately, end-users may use their storage in net metering situations as some renewables are used today – to sell power back to the grid at peak times. Whether storage economics will make this viable is an open question.

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

A very specialized end user application, under investigation in Europe and by NYSERDA, is the use of storage to levelize the peak power demands of electric rail operations and reduce rail power distribution losses. Trains consume as much as 75% of their power when they are accelerating out of a station. Storage deployed at stations would reduce the losses in delivering power to the train (catenary losses are quite high – more than double typical T&D losses due to the need to use steel for catenary conductor) and can capture regenerative braking as well. Using storage avoids having to perform expensive or impractical retrofits to the trainsets themselves, as would be necessary for the use of flywheels for similar purposes.

Other niche applications include cranes, container ports, and other applications characterized by short bursts of peaking power where managing local demand and/or losses is of value.

These applications are mentioned only as a way to illustrate that many other high value end user applications will come forth once the storage technology is proven. Exhibit 1-4 shows the applications and value propositions that could be derived from storage.

Exhibit 1-4: Storage Applications

Application	Benefit	Quantification	Power Requirement	Duration	Comments
Storing renewable DG production	capture renewable DG production for use when wanted and reduce grid consumption; mitigate capacity charges as well		equal to local DG peak production	hours	
Time shifting of demand to avoid peak prices	avoid high real time prices at peak		equal or less than peak load	hours	
Price arbitraging in real time pricing situation	same as for storage in generation balancing energy		as desired	30 minutes	not allowed under existing tariffs
Reliability enhancement	avoid interruptions	linked to value of production and cost of interruption	equal to peak load protected	minutes to hours	linked to DR and backup generation
utilty reliability enhancement	allow utility control for targeted enhancement	linked to utility capital deferral	equal to peak load typically	minutes to hours	unexplored but potentially attractive in urban situations
PHEV integration	lower cost of charging by only using off peak power	lower cost of driving plus utility capital deferral	equal to vehicle power draw	hours	
Demand Response integration	make DR participation in markets more attractive			minutes to hours	commercially being investigated today
Renewable Demand Response	Renewable volatility and difficulty of control make them unreliable for demand response applications. Storage can be an enabler.				
Railroad acceleration support	avoid significant I2R losses	5-10% of energy bill?	10 MW per station	minutes to hours	being investigated today

2. Regulatory Issues and Potential Barriers to Adding Storage

Energy storage faces certain regulatory hurdles in allowing for its use in the electric industry. Like any new or emerging technology, energy storage has a lack of regulatory history to guide people on its use. In addition, there is no overall strategy or policy on how energy storage can be incorporated into existing components of the industry. In fact, there are few regulations that address energy storage directly at all. The lack of any direct regulations leaves utilities uncertain over how energy storage will be treated, how costs would be recovered, or even whether energy storage will be allowed in a particular regulatory environment.

The main reason for the lack of regulations is that electric storage on a utility scale basis is very uncommon, and except for pumped storage, is relegated to pilot projects or one-off situations. Utilities have not used storage to address issues and are perhaps not used to thinking about how to use a non-traditional technology such as storage to address issues in ways different than done in the past. An additional reason for the uncertainty over the treatment of energy storage stems from whether energy storage is seen as more related to generation or transmission. The problem, from a regulatory perspective, is that energy storage can provide functions related to both. The bulk storage of electricity, for example, if used by a utility to time-shift the generation of electricity from a time of low-cost generation, such as in the middle of the night, to a time of high-cost generation, such as during peak use, would be seen as similar to generation. On the other hand, in addition to reducing or eliminating the need for peaking facilities, this type of action could also reduce transmission congestion, provide voltage support at a time of peak use, and provide other ancillary services. The ability of energy storage by utilities to perform multiple roles gives rise to the confusion of how energy storage should be regulated. In addition, the multiple roles of energy storage spread out the benefits that storage provides as well as the income streams provided by these benefits. Because of this indeterminate state, utilities are reluctant to roll out large-scale energy storage projects. Finally, energy storage can also be used at the customer level in a role similar to a distributed generation facility, for back-up generation or arbitrage for electricity price on the spot market.

This confusion affects the cost recovery status of energy storage projects. Because of the multiple roles that energy storage can play, utilities are unsure of how to classify energy storage projects, and are uncertain that a basis can be asserted for the cost recovery. If an energy storage project is compared directly to a peaking generation facility, or to developing a new transmission line, without taking into account the different benefits of energy storage, the cost of the energy storage project may not seem justified if the problem can be addressed through a less expensive manner. However, it may be difficult to quantify or compare the costs and benefits of all the different functions provided by an energy storage project to a single generation or transmission project.

Because of the multiple benefits that can be provided by storage, the potential income streams provided by storage are also diverse. For example, a storage project may provide benefits of improved reliability, deferral of transmission improvements, and firming of renewable generation. The issue is how to monetize the value that is provided by each of these benefits. Arbitrage for generation or the provision of ancillary services would not provide sufficient income if these were considered individually, but combining multiple income streams would allow for cost recovery of the storage project. However, going back to the original “problem,” because these benefits address different functions (generation vs. transmission), it may be difficult to measure the different benefits and allow for full cost recovery based on these benefits.

Another problem relating to cost recovery and encouraging energy storage is that if a utility is guaranteed to receive recovery of a transmission or generation project, or both, the utility has no incentive to put an energy storage project in place. Rather than address an issue through the use of energy storage, a utility may simply opt to construct a transmission or generation facility, or both, the costs of which are more likely to be recovered. Also, a regulatory body may be less inclined to allow cost recovery for a new or untested storage technology, rather than burden the ratepayer with technology that may not provide the advertised benefits. In this respect, regulatory agencies may seem more conservative and rely on proven technology to address issues that could be solved through storage.

One area where energy storage could provide great benefits is in conjunction with renewable resources. By storing energy from variable resources such as wind and solar, storage could provide firm generation from these units, allow the energy produced to be used more efficiently, and provide ancillary transmission benefits. However, the production tax credit, which is currently applied to wind generation, does not extend to associated storage. Nor is storage included in other incentives for renewable generation. Generators, or residential customers for small scale renewable generation, may use storage for arbitrage purposes, but as explained above, the revenue from arbitrage does not cover costs of a storage project. Without including storage in the incentive package, or providing separate incentives for storage, it will not be used with renewable generation.

In encouraging storage use among electric customers, the current pricing structure of flat rates does not provide any incentive for the use of storage. Customers can take advantage of price differentials between low and peak demand, although without other incentives relying solely on pricing arbitrage does not provide enough savings or cost recovery for the use of storage. Storage for larger customers may provide other benefits, such as reducing or eliminating demand charges. Storage for all customers could also be used for demand management programs, provided that there is an extra incentive associated with this benefit for the consumer.

The first thing that must be done to address the regulatory obstacles is to define storage and provide regulations on its use. If storage is used by a specific market segment, its use should be defined so as to not “stray” into other areas. However, the appropriate incentives or allowances for cost recovery should be made by either allowing the storage owner to obtain multiple income streams to support the storage costs or to allow cost recovery through rates. By simply addressing the issue of storage and indicating that storage is an option that is available to market participants, storage will overcome its largest hurdle. With regulations that encourage its use, market participants will know with certainty that storage can be used, along with more traditional tools, to address market issues.

3. Growth of Storage in PHEVs and the Impact on the Future Smart Grid

It is likely that plug-in hybrid vehicles (PHEV's), vehicles that have an all-electric range of approximately forty miles will penetrate the US market in significant numbers in the near future. While the exact timetable is uncertain, most agree the trend will start beginning in 2010 and will be in full swing by 2050. One study[1] predicts a deployment of 30% of new light vehicle sales by 2030. The study suggests, "Plug-in hybrid vehicles, building upon the engineering and market acceptance of traditional hybrids, are expected to enter the U.S. market around 2010, and to gain market penetration through 2050 because of their superior fuel performance and environmental benefits."

Another study[2] concludes that with "proper changes in the operational paradigm, it (the US electric system) could generate and deliver the necessary energy to fuel the majority of the U.S. light duty vehicle fleet." The report does not address any additional benefits or costs of vehicle-to-grid electric power generation or spinning reserve services that PHEVs may provide in the future. PHEV's are one of a cadre of technologies that can provide a way to deal with climate change (reducing CO2, NOx, SOx,Mercury, etc.), energy security (eliminating oil as a strategic commodity), and the rising costs of transportation.

PHEV's will rely principally on the electric grid for their fuel. At present there are some 70 new hybrid vehicles planned for 2010 by various manufactures around the world. It is estimated that by 2016 there will be two million hybrids on the road in the US. The plug in hybrid design is thought by some to be the next logical step on a path to a future of pure electric vehicles with a 300 mile range and short charge times.

In this section we discuss the potential impact of a significant penetration of PHEVs on the electric system both in terms of the increased demand they will present but also the possible

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[1] The Power to Reduce CO2 Emissions: *The Full Portfolio*, Discussion Paper Prepared for the EPRI 2007 Summer Seminar Attendees By The EPRI Energy Technology Assessment Center, August 2007.

[2] Impacts Assessment Of Plug-In Hybrid Vehicles On Electric Utilities And Regional U.S. Power Grids Part 1: Technical Analysis, Michael Kintner-Meyer, Kevin Schneider, Robert Pratt, Pacific Northwest National Laboratory Report, 2007

benefits of using the distributed storage they could offer. This is called “V2G” and produces what some call the “cashback hybrid” approach.

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

Today, the average commuter drives less than 40 miles a day. A plug-in hybrid is a HEV with a much larger battery pack (5 – 10 kWh) and the ability to operate for 20 to 40 miles in an electric-only mode. The combustion engines are smaller (the GM Volt will likely use a 1.4 L non-turbo 4 cylinder engine as its range extender), and can be optimized as they function as a generator to charge the batteries using on-board fuel. PHEV’s store enough electricity, presumably from an overnight charge, for the first 40 or so miles to be driven solely on electrical power. Beyond this range, they function like HEV’s. They are intended to be charged from the grid and the small combustion engine would only be used when the car’s battery is substantially depleted of charge.

In addition, and in parallel, there is a move to create a Smart Grid that will contain a high level of smart technologies; that is, technologies with embedded computers that collectively can provide a network of distributed intelligence. The Smart Grid will incorporate standardized communication protocols, affording significant interoperability with other devices. And it will be integrated with a smart electricity infrastructure at the distribution level, with the energy management system (EMS) at the transmission level, and with grid operations and planning. Some predict this vision will be implemented by 2025. One study[1] suggests that, “With parallel advances in smart vehicles and the smart grid, PHEVs will become an integral part of the distribution system itself within 20 years, providing storage, emergency supply, and grid stability.” The confluence of advances in batteries and grid intelligence provide the potential to transform the transportation sector over the next 20 years.

3.1 A Three-Phase Approach

At present, most experts agree that the adoption of PHEV's will begin in the short term with vehicle charging managed only by pricing. This so-called "G2V" concept would give cost benefits to those agreeing to charge their vehicles at night, thus filling in the load valley, and penalize those charging during the day. There are approximately 54 million garages for the 247 million registered passenger vehicles in the U.S. today. Since most consumers without garages do not have a way to charge a plug-in vehicle, there is a substantial amount of infrastructure that must be built. Fortunately, that work has already begun with companies like Coulomb Technologies offering products and services that provide a smart charging infrastructure for plug-in vehicles. Successful management of charging in the long run will require significant deployment of smart grid technologies. But that will take some time to complete.

The prospects for any PHEV charging today are limited to vehicle ownership that can provide a nightly parking / garaging location with access to a power outlet. This is a challenge for the vast number of owners that rely on street or parking lots for nighttime parking. As noted above, the vast majority of US automobiles are not garaged. The distribution of early PHEV sales may well tend to owners with garages, and the lack of a convenient charging location may also influence buying decisions. However, long term this is a critical infrastructure need if PHEV and EV are to become the dominant vehicle in the US fleet. Even when owners have garages, it is not uncommon in many geographies to see cars parked in driveways – whether because the household owns more cars than garage space or because the garage is used as storage, workshop, etc. A long term solution that has extension cords strung across driveways, parking lots, and parking garages is not a desirable future for the US.

Owning a PHEV and recharging it every night from a minimum charge level would increase the average US residence electric consumption by approximately 50%. For a 40 mile range PHEV the maximum consumption would be about 14kWh. An average household with a monthly consumption of 850 kWh would increase its demand by at most about 420 kWh. According to the Pacific Northwest National Laboratory 2007 Report referenced earlier [2] "Providing 73% of the daily energy requirements of the U.S. LDV fleet with electricity would add approximately 910 billion kWh…" to the current load. While this is an energy load, it is also a potential source of energy storage. If we assume a uniform distribution of battery charge, that cars are driven on average 2 hours a day, and when not in use are available for use by a utility, this means on average there would be 417 billion kWh's of storage available for discharge or charge. This capability is valuable for peak-shaving, valley filling, and spinning reserve for guarding against losses due to contingencies.

A major question is how PHEV usage will interact with high levels of renewable generation, especially wind and solar. Renewable generation has strong diurnal characteristics that are obvious with solar and which vary somewhat according to geography with wind. If PHEV charging load matches peak renewable production, then the industry has a "marriage made in heaven." If the PHEV charging does not match daily renewable cycles well, then the mismatch is problematic and storage has an even more important role to play in supporting high renewable portfolio standards.

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

And finally, in the long term the V2G concept is envisioned where there is full bidirectional controlled flow between the vehicle and the grid. Control of the bidirectional electric flow could include payments to owners for use of their car batteries for load leveling or regulation and for spinning reserve. This is the “Cashback Hybrid” incentive. Kempert and Wellinghoff [x] say that “It is our opinion that the potential benefits of vehicle-to-grid (V2G) PHEVs (or the “CashBack” hybrid) are so compelling that the technology is clearly an enabler of both the “smart grid” and the successful market penetration of the PHEV itself.” In Fortnightly[3] the authors indicate that the payments to individual PHEV owners using V2G technology could be as much as $2,000 to $4,000 per year per vehicle for just spinning reserve or regulation services. Because the flow of energy is bidirectional, electric service providers can benefit in addition to PHEV owners by controlling or at least monitoring the flow between PHEVs and the grid. Possible benefits to utilities include the ancillary services mentioned earlier plus demand response assistance from PHEVs, and green power credits.

In order to support this model, considerable work needs to be done to develop the market protocols, information exchange standards, and possibly the electronic interfaces that will

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[3] S. Letendre , P. Denholm and P. Lilienthal of NREL, Public Utilities Fortnightly, December, 2006

govern V2G integration and interaction. PHEV will bring together the entire value chains of the automotive/transport sectors and the electric supply sectors – which do not share common standards or standards bodies today.

To implement this concept 3rd party ownership of batteries may be needed. The term “third party” is defined as an entity other than the PHEV owner or the auto manufacturer and might include an electric service provider, a generic profit center, an IT company such as Google, or an emissions credit trading organization. Consumer benefits might include a free or reduced price battery accompanied with warranty service to ensure performance, reliability, and safety. Also, automotive OEM or third party ownership of the batteries will likely enhance the prospects of environmentally secure end of life disposable of the batteries, a non-trivial issue. Furthermore, there is a possibility that after batteries have reached end of useful life for vehicular purposes (degradation of charge capacity reducing vehicle range) they will still have economic use in power back-up or utility applications, suitably repackaged. This prospect, coupled with the possibility of a vehicle retrofit with a higher performance battery – later technology – is very real. However, the first generation PHEV vehicles will not include V2G capability primarily due to warranty concerns about the batteries and a desire to avoid additional complexity and cost.

3.2 Where are We

In July 2008, General Motors announced that it is collaborating with 34 utilities and EPRI to ready the nation's electric infrastructure for the widespread sale of plug-in electric cars, such as the Chevrolet Volt. This is a landmark, first of its kind effort through which GM will work directly with utility companies and EPRI to ensure that the codes, standards, and grid capabilities are in place so that when the Chevy Volt comes to market, the infrastructure will be there to support it. This collaboration involves 34 utility companies spanning 37 states and 3 Canadian provinces. Most of the major utility companies are represented and as a whole serve a very large volume of the US population. It has a far greater and more powerful scope than simply working with EPRI as other automakers already are currently doing. Even so, neither EPRI nor GM can unilaterally speak for their respective industries and supply chains, so that it will be important going forward to see that this is open and responsive to a broad range of industry participants from both sectors.

The most influential factors on the PHEV industry between now and 2030 are probably regulatory requirements, including consumption regulations, carbon taxes, and emission standards. Technology breakthroughs, primarily in batteries, manufacturing technology advancements and deployment, incentives for early adopters, and the development of industry standards for components and technologies are also important factors. The next generation of vehicle purchasers is expected to be more conscious of green benefits and to be aware of the negative effects of emissions. Nevertheless, the US appears to be on a path to adoption of a significant number of PHEV's and the electric grid will have a central role in assuring their adoption.

3.3 Regulatory and Institutional Policy Issues

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

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

Renewable generation development already is the subject of federal and state tax incentives such as the Production Tax Credit. PHEV and EV were awarded incentives up to $7500 per vehicle in the Financial Bailout package passed by Congress on October 3, 2008. In addition, they will likely benefit from direct tax incentives to suppliers or purchasers as well as locally specific indirect incentives (HOV lane access, parking access for instance, as well as subsidized employer charging). There already is concern about how to replace (hopefully) declining gasoline tax revenues that support highway infrastructure. In the event that PHEV adoption succeeds wildly, an important question will be how to fund utility infrastructure to support PHEV. Should it be socialized through general T&D tariff increases or funded incrementally via a mechanism tied to local PHEV sales, or via some other mechanism. This is a potentially important question that emphasizes the need to understand well the specific local and regional infrastructure needs to support different levels of PHEV and EV adoption.

4. Meeting the Mandates of the Energy Security and Independence Act of 2007

Achieving the goal of Energy Storage Competitiveness for the United States will require a focused effort by DOR, American business and Academia. Subtitle D of the 2007 Act outlines the areas of concern in achieving this goal with the associated levels of funding. Helping energy storage reach full potential in the utility and transportation sectors will need a sustained effort with at least a five-year period. Examples of support for action in this arena continue to grow with recent positioning by the Institute of Electrical and Electronic Engineers (IEEE) and the American Institute of Chemical Engineers (AICHE) on Plug-In Electric Hybrid Vehicles and Massive Electricity Storage in the utility grid.

4.1 Research & Development Efforts

Making energy storage a vital part of the nation's energy future starts with storage systems that have greater energy and longer discharge times. The demands of transport applications will always value high energy densities (in joules / kg and/or joules/cubic meter) more highly than grid connected applications. Thus the R&D efforts going on to improve EV batteries, for instance, may develop new materials which are superior in these regards but at continuing high price points. The life cycle of the battery in terms of lifetime charge-discharge cycles will be dictated by expected vehicle warranty and lifetime considerations and overall cost of driving. By contrast, large scale utility applications will place a higher value on the scale that can be achieved at moderate cost and utility timeframes for life cycles are typically measured in decades.

Therefore, the battery materials research drivers for EV applications and utility applications diverge over the priorities of different performance metrics. Today, utility storage applications are being piloted based on technology derived from EV targeted applications - but the cost parameters limit the usefulness of these technologies to specialized ancillary services. Continued DOE efforts in materials research and storage technologies for grid applications should be encouraged and not lost in the focus on the transport sector.

Although the primary focus is batteries, improving the performance of large-scale systems like compressed air energy storage should receive support as well to insure the entire spectrum of devices are advanced. The areas of R&D activities that should receive attention are:

- Establishment of programs for rapid, broad and large-scale materials evaluation and screening tied to energy storage applications. These programs need to radically accelerate the screen process using supercomputer techniques applied in biological sciences to create a “material genome” concept.

- Establish the centers of excellence currently under solicitation by the DOE Office of Science and provide long-term funding (at least five years) for these activities.

- Support collaborative, inter-disciplinary research between the DOE laboratories and universities and industry partners such as EPRI, auto manufacturers and technology centers such as the Southern California Edison (SCE) electric transportation lab.

4.2 Applied Research and Demonstration Activities

In both the areas of new energy storage devices for utility and transportation applications, new storage systems are beginning to reach the market. Expanding activities to test more applications at small and large scales need to be supported. These activities should include expanded analysis of business cases and value propositions for energy storage of all types. These activities should include:

- Fund studies to consider the full scope of what is required to commercialize a domestic and international advanced battery market for vehicles, stationary and utility applications. This would include examining all stages of market development from basic research to a functioning market, including comparing our efforts with other countries determining if there are market or institutional or financial barriers and how to remove them.

- Provide increased funding to help accelerate the improvement in weight, size, cost, life and safety of batteries for plug-in vehicles.

- Fund demonstration activities that test the performance of smart-grid technologies interacting with energy storage in the grid. This effort should include PHEVs as a part of the load.

- Support applications of battery and flywheel energy storage for ancillary services use in frequency regulation of the grid. Specifically target the use of storage to provide a new “short term” reserve product in the market intended to bridge the gap before additional traditional generation can be brought on line

- Support demonstration projects targeted at analyzing use of large-scale energy storage to help offset curtailment of wind energy in areas with transmission constraints. This effort should include collaboration with EPRIs's CAES initiative.
- Support demonstration projects in utility distribution networks to measure grid performance improvements regarding reduced T&D losses and system reliability improvement.

4.3 Measuring Program Success

As with any complex program, measuring success is difficult but metrics should be established to determine progress. The following recommendations are made:

NEAR TERM (3 – 5 years)

- Accomplish the materials genome project for analysis of materials for energy storage use.
- Complete detailed studies on the effects of higher penetration of renewable sources on grid operations with the permanent retirement of a large percentage of traditional generation.
- Complete at least three large scale demonstration projects that examine the performance of smart grid technologies interacting with storage in the grid.
- Establish the four Energy Storage Research Centers specified in the Act of 2007
- Provide funding up to 30% of the cost of storage used to demonstrate the performance of the objectives cited above.

MID-TERM (6 – 12 years)

- Continue to fund (up to 30%) storage projects that expand the use of storage for grid performance enhancement and show benefit to in the use of renewables.
- Measure and report the impact of PHEV's and EV's on performance of the utility grid in terms of peak loading and any change in the need for ancillary services.
- Fund R&D activities that result from recommendations of the materials genome project above.

- Fund larger scale demonstrations of energy storage for transportation to include large trucks and rail applications

LONG-TERM (2020 and Beyond)

- Implement programs to test and analyze V2G performance and the impact on utility grid operations.

5. Recommendations and Actions

The nation's goal of reducing dependence on fossil fuels and cleaning the environment is an enormous task, which will require major technological innovations. Energy storage will be the major contributor in the transportation sector and play a role in the utility grid as well. The major recommendations and actions by this subcommittee are:

"Suggestions"

- Establish financial incentives for building and operating storage facilities in the grid to enhance the use and value of renewable energy resources.
- Establish five-year benchmarks for size, weight and cost targets for batteries used in plug-in vehicles.
- Consider using energy storage as primary source of frequency regulation control in the nationwide grid to free up coal and natural gas generation assets for real power production.

6. References

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

IEEE-USA Position Statement – "Plug-in Electric Hybrid Vehicles",
June 15, 2007

AICHE White Paper – "Massive Electricity Storage", June 2008