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Market Driven Distributed Energy Storage Requirements for Load Management Applications

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Market Driven Distributed Energy Storage System Requirements for Load Management Applications

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Technical Update, April 2007

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Electric Power Research Institute (EPRI)

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This report describes research sponsored by the Electric Power Research Institute (EPRI).

This publication is a corporate document that should be cited in the literature in the following manner:

Market Driven Distributed Energy Storage System Requirements for Load Management Applications. EPRI, Palo Alto, CA: 2007. 1014668.

PRODUCT DESCRIPTION

Electric energy storage systems are an enabling technology that could help meet the needs of electric utility by managing peak energy demands, helping shift the peak loads to off peak hours and improving the load factor of the electric distribution system. Applications of distributed energy storage systems (DESS) could also provide power quality and reliability benefits to customers and to the electric system. EPRI collaborated with several investor owned utilities to conduct a study to understand the technical and market requirements for distributed energy storage systems to enable customer and electric system load management.

Results

- Market potential emerges when the cost of the energy storage component in a fully integrated DESS falls below $100/kWh. Considering the total societal benefits (utility benefits plus customer benefits), the cost of the fully integrated DESS should be between ~$150/kWh to $250/kWh (or $600/kW to $1,000/kW for 4 hour storage capacity) for mass market adoption.
- The size of DESS for residential applications ranged between 1and 5 kW with 5 kWh to 30 kWh storage capacity. For the majority of commercial applications, the size ranges between 30 and 150 kW with 100 kWh to 1,500 kWh storage capacity.
- The implications of commercially viable DESS on a national basis could range from 20 GW to 150 GW if the cost of the energy storage component in a fully integrated DESS falls in the range of $ 80/kWh to $20/kWh respectively.[1] Current technology, however, is a factor of 2 to 5 times this level.
- The analysis showed electric utilities are optimum early adopters and operators of DESS rather than end-use customers because: 1) the technical and performance requirements are less demanding than those required for customer adoption, and 2) these systems could be used by electric utilities to maximize the efficiency of the electric distribution system operations and 3) the societal benefits could be more easily monetized.

Objectives: The project objectives were to:

1. Define DESS parameters suitable for various customer segments based on potential economic values to both customers and utilities;
2. Assess the cost and benefits of DESS from both the end-user, utility system and society perspectives and identify the most sensitive parameters;

---

[1] The total cost of any storage plant is equal to : Cost for Power Component or the balance of plant in ($/kW) + hours of discharge storage time multiplied by the cost of energy storage component in ($/kWh)

3. Estimate the US load impacts of DESS based on extrapolation of analysis from several large investor owned utility systems;
4. Determine DESS size requirements for residential and commercial sectors;
5. Document the findings and transfer results to industry stakeholders, vendors and researchers.

EPRI Perspective

This study estimates key technical and performance parameters necessary for DESS to be competitive in commercial and residential market segments under present rate and retail price assumptions. The results, however, were derived from a limited sample of investor utility data and may not be entirely representative of the entire US market. The results may also not represent the market needs in the rural or municipal utility sectors. The analysis of the value of distributed storage can be very system and site specific. This study also did not examine the cost and value for other applications for DESS, such as with renewable power systems. Follow on research is needed to assess the market requirements for those applications with industry stakeholders. An EPRI sponsored Technical Innovation project has started this process and some preliminary results are provided in Appendix D of this report.

Approach

A technical and economic market analysis was conducted with several large investor owned utility systems to understand the cost and economic requirements for DESS. An electric utility systems' oriented approach was used which assumed electric utilities would own and dispatch the systems. Also, an end-user oriented analysis was performed assuming end-user ownership and dispatch. In both cases a "black box" fully integrated distributed energy storage system was assumed and analyzed using present electric rates.

Keywords

Electric Energy Storage
Distributed Energy Resources
Markets Analysis

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1

INTRODUCTION

Low cost and reliable electricity is a critical economic growth driver in the United States. The use of distributed energy storage systems (DESS) could help meet utility[2] needs in meeting demand and managing associated peaks. Systems which store electricity during off-peak hours and use it during on-peak hours to reduce the peak load demand could provide benefits to both electric utilities and end-users. Such systems could provide utilities with an option to shift load to off peak hours and increase the utilization of grid assets, thereby improving system load factor. Such applications could also provide utilities with added end-user service offerings in the form of power quality and added reliability. This could provide customer satisfaction benefits for the utilities and greater customer flexibility and choice.

DESS which utilize battery and other energy storage technologies could help utilities and their customers overcome increased costs often associated with peak demand. Although there are technologies available in the market, only a limited number of system providers exist today that can provide and deliver fully integrated storage systems at affordable prices. Fortunately, storage technologies continue to advance[3] and there are technologies in the R&D pipeline which could be used in stationary distributed energy storage applications. Also, vendors and system integrators developing energy storage products may be unaware of the electric utility market electricity storage needs. See Table 3-1 in Chapter 3 for a listing of current available energy storage technologies and the references in Appendix A for a more detailed description on the status and trends of energy storage systems.

In this report the following terminology is used:

- A fully integrated DESS consists of the energy storage component and the balance of plant to enable a fully functional, dispatchable and grid interconnected unit.
- The energy storage component of an integrated system stores and releases kWhs. In this study, it refers to the battery component. It does not include balance plant equipment.
- The balance of plant equipment (BOP) includes the power conditioning system, thermal management systems and communication & controls.
- The power conditioning system (PCS) consists of the inverter and associated controls. The inverter is a solid state device which converts dc voltages into ac voltages compatible with the grid, and delivers the necessary power (kW) rating of the system. In this study the inverter was assumed to be the dominate cost element of the BOP.

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[2] In this report "utility" is defined as either an electric distribution company or a vertically integrated utility. Some of the distributed benefits detailed in this report may be under estimated for fully integrated utilities that operate generation assets.

[3] The growing trend in hybrid and plug-in hybrid vehicles is creating an opportunity to leverage R&D investments in advanced batteries for stationary distributed energy storage applications.

- The total cost of a fully integrated DESS is the combination of the cost of energy storage component and BOP. A mathematic relationship of the cost is shown below.

$$DESS(\$/kWh) = EnergyStorageComponent(\$/kWh) + \frac{BOP(\$/kW)}{Hrs\_of\_Storage} \quad \text{or}$$

$$DESS(\$/kW) = EnergyStorageComponent(\$/kWh)x(hrs\_of\_Storage) + BOP(\$/kW)$$

This project seeks to understand the electric utility system and end-user requirements for DESS. This report and the results will help facilitate an electric utility industry market-driven process that will engage the utility industry stakeholders with energy storage vendors and system integrators and to help drive energy storage technology R&D and product development towards a successful commercialization pathway of value for the electric enterprise.

Objectives

The overall goals of this project are to identify specific requirements, including technical, functional and economic criteria for DESS to serve electric system and end-users needs. The project is also intended to identify and scope the costs and benefits of fully integrated DESS from different stakeholder perspectives including electric utilities and end-users resulting in societal benefits. Specific project objectives are detailed below:

1. Define DESS parameters suitable for various customer segments based on potential economic values to both utilities and customers;
2. Assess the cost and benefits of DESS from both the utility system, end-user and resulting society perspectives and identify the most sensitive parameters;
3. Estimate the US load impacts of DESS based on extrapolation of analysis from several large investor owned utility systems;
4. Determine DESS size requirements for residential and commercial sectors;
5. Document the findings and transfer results to industry stakeholders, vendors, and researchers.

Approach

The market requirements for a fully integrated and installed DESS were estimated using two approaches: 1) a utility business model; and 2) an end-user business model. In each approach, a life-cycle analysis was used to estimate the value of energy storage. This includes the total cost of capital, installation, operation and maintenance costs evaluated over the life of the battery system.

Utility Business Model

The economic costs and benefits for DESS were estimated from an electric utility system's perspective in an analytic and modeling effort. EPRI contracted Energy and Environmental Economics to perform this work based on previous methodology used to assess the cost and benefits of distributed energy resources (Reference 4 in Appendix A). Details of the input assumptions and the model can be found in Appendix B. The objective was to estimate the magnitude and range and the DESS benefits, if such systems were owned and dispatched by an electric utility. Input assumptions considered energy and capacity values for each hour of the year and included: distribution capacity; transmission capacity; generation capacity and energy values. Proxies for utility values were used to estimate the value of energy storage from the electric system's perspective[4].

Sensitivity analysis of key input parameters was also performed to show the impact of key assumptions.

A life-cycle analysis was used to estimate the value of DESS. This includes the total cost of capital, installation, operation and maintenance costs evaluated over the life of the system.

It is important to note that the analysis and results presented in the next section are based on present utility rates. The impact of possible future rate changes to the results of this study were not addressed.

End-User Business Model

In the end-user analysis approach, a business model was used which assumed end-users owned and dispatched the DESS to save energy costs. A "black box" fully integrated DESS was presumed to be installed at customer locations in the service territory of several investor owned utilities. These large investor owned utilities represented about 30 % of the U.S. market and had customers that cover a wide range of geographical areas and end-user segments. Analysis of both commercial and residential market segments was performed using present rate methodologies to determine the ideal system sizes (in terms of both peak capacity and energy component) and the allowable economic installed cost from the end-user's perspective.

Resource Dynamics Corporation's Distributed Power Economic Rationale Selection (DISPERSE) model was used to estimate the achievable technical and economic market potential for storage systems by comparing on-site storage economics with competing grid prices. The model not only determined whether storage is more cost effective, but also which energy storage sizes appear to be the most economic to meet facility load and energy needs. The model was developed over the past seven years and has been used in a variety of distributed energy resource

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[4] The value streams used as proxies in the energy storage model were based on the adopted values in the energy efficiency proceeding, California Public Utility Commission Rulemaking 04-04-25. The report can be downloaded at the following URL. http://www.ethree.com/CPUC/E3_Avoided_Costs_Final.pdf

(DER) peak shaving, base load, and combined heat and power (CHP) assessments for utilities, equipment manufacturers, and research organizations.

Figure 1-1 below provides an overview of the model inputs, analysis, and output in an electric energy storage analysis for end-users. .

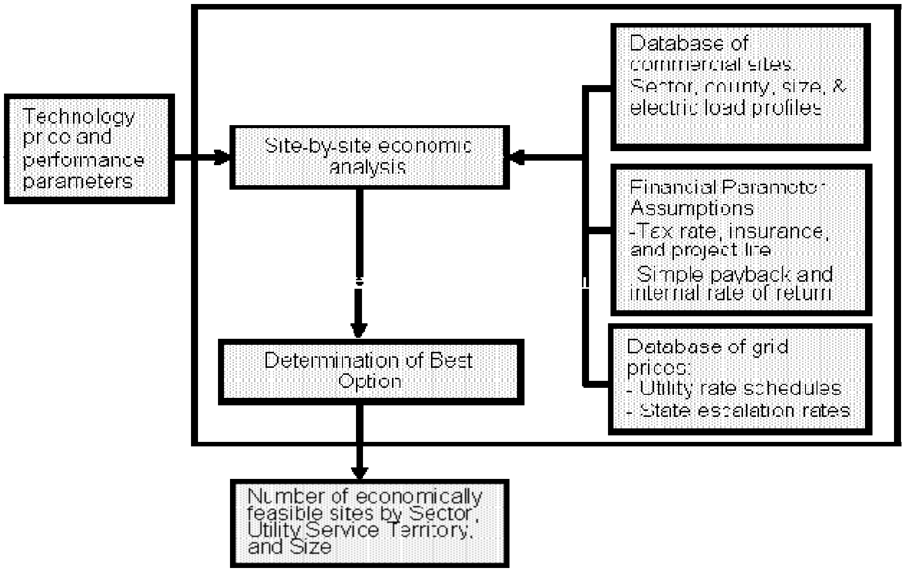

Figure 1-1
End-User Analysis Approach

The model run begins with a database of commercial and residential sites, which are organized by region, NAICS/SIC code and size. In addition, based on the site SIC code, the model assigned an electric load profile representative of that customer building type. The size of facility was used to “scale” up or down the magnitude of the load profile. The load profiles for the commercial sector in the DISPERSE model were derived from the Department of Energy’s DOE-2 model. Load profiles are by building types (e.g. office building, restaurant, school) and location (e.g., Philadelphia). Each facility was assigned a building type/location, based on the SIC and geographic region. Regional residential load profiles were provided by EPRI and the participating utilities.

Using this information, combined with the baseline energy storage price and performance data, the model performed a life-cycle cost economic analysis, determining year 1 savings from using the electric storage system. The model then compared savings from storage systems with costs of purchasing from the grid (from the database of grid prices), and counted the application if it provided “bill savings” with a sufficient payback. This process was repeated tens of thousands of times, once for each group of sites with the same region/size range/SIC code, and the results were then aggregated to obtain market potential.

An iterative process was used to determine peak capacity and energy storage ratings and sizes and costs that lead to economically-viable applications for a given customer type (NAICS/SIC codes or building type). To perform this step, the model was run with different sets of technology price and performance data (i.e. low/high cost, low/high storage capacity). Iterations were also made holding the price and performance constant and finding what rate structure could lead to favorable economics.

For end-user's, the DESS could be used to reduce either: peak demand (which would result in lower demand charges) or electricity consumption during on-peak hours; or they could be operated during periods of time when wholesale electricity was expensive (in a demand response role). An iterative analysis was used in determining which combinations of the three main variables (installed cost, peak capacity (power), and energy ratings of the energy storage component) made the energy storage systems competitive. Results were extrapolated to estimate a rough U.S. market size estimate. Given the number of variables, the approach was tailored to vary the more sensitive parameters such as the cost of energy storage component, while initially fixing the less sensitive parameters such as the cost of the BOP, storage life, and overall efficiency.

Cost targets for the BOP were assumed to be based on the discounted pricing of inverter/charger systems used for current photovoltaic solar system battery energy storage applications. It was also assumed that the remaining component costs for BOP and installation could be included in the base case costs presented when they reach mass production at volume of hundreds of thousands of units.

The baseline analysis focused on the inverter/BOP costing from \$400/kW for smaller residential sites dropping to \$200/kW for larger commercial sites. Sensitivity analysis was conducted with inverter/BOP costs double these (\$800/kW dropping to \$400/kW).

2
RESULTS

This section provides a summary of the analysis results. The potential economic/societal value of DESS from a utility business model perspective (utility owned and dispatched) is presented first, followed by the findings from the end-user business model (customer owned and dispatched).

Utility Business Model-Utility Owned and Dispatched DESS

Results

An analysis was performed to estimate the range of values for utility-owned and dispatched DESS based on underlying utility system costs and assumptions regarding the performance of the DESS. The lifecycle costs and benefits of energy storage applications from utility, customer and societal perspectives were evaluated to understand the potential value. Definitions of terms used for the input assumptions and model outputs is provided in Appendix B. A promising DESS would have to cost less than the lifecycle net benefits from a societal perspective, and a promising DESS utility program would make both the utility and customer better off to achieve a "win-win" outcome.

The costs, benefits and net benefits for residential and commercial applications are shown in Figures 2-1 and 2-2 using proxies for key input parameters. The base case results for the residential analysis, shown in Figure 2-1, illustrates the estimated benefits and the economic value of DESS of $ 148/kWh ($ 592/kW) for a four-hour storage system. Given assumptions about utility system costs, the DESS was economic to dispatch ~ 80 cycles per year and resulted in net utility benefits of $89/kWh including lost revenue due to time-of-use pricing differential of a residential customer. The customer value in this analysis is $ 59/kWh. Therefore, if the <u>fully integrated</u> DESS costs less than $148/kWh installed, it should be possible in this scenario for a utility to purchase the system and install it at a customer site in return for a customer payment (up to $59/kWh) and still have a net positive benefit. This would be a 'win-win' to both the customer and utility.

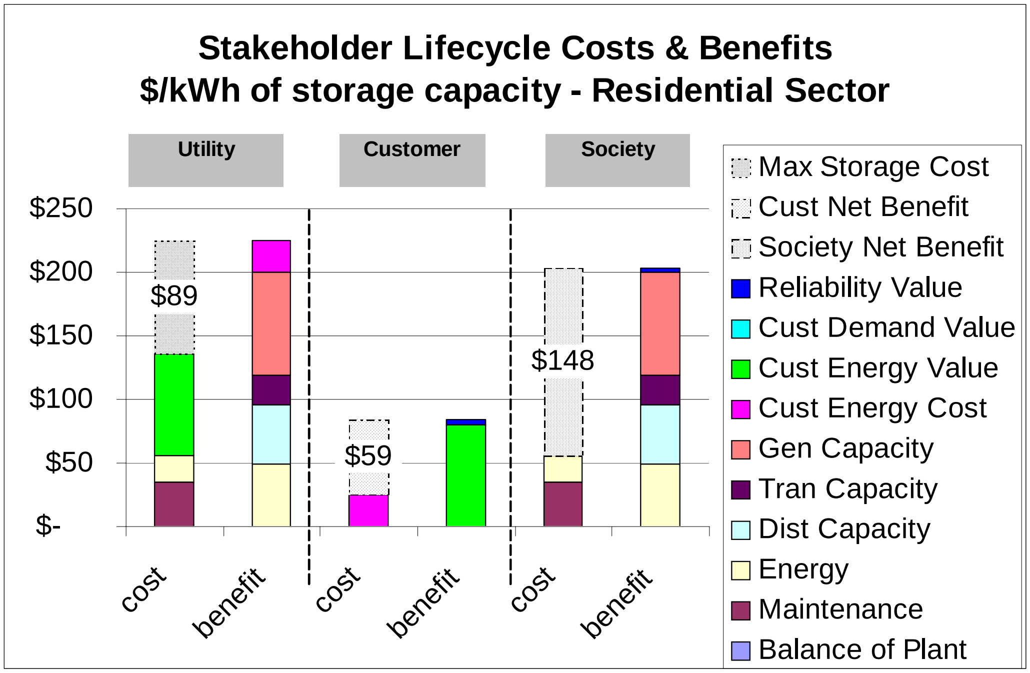

Figure 2-1
Residential Sector Utility Owned and Dispatched Energy Storage System

Results for the commercial market segment applications are shown in Figure 2-2, using the same assumptions about the DESS, utility system costs and the dispatch of the energy storage system. However, since the rate structures for the commercial application are different (lower time of use price differential and the inclusion of a demand charge) the customer bill savings in this segment is lower ($29/kWh) and the utility net benefits is higher ($119/kWh).

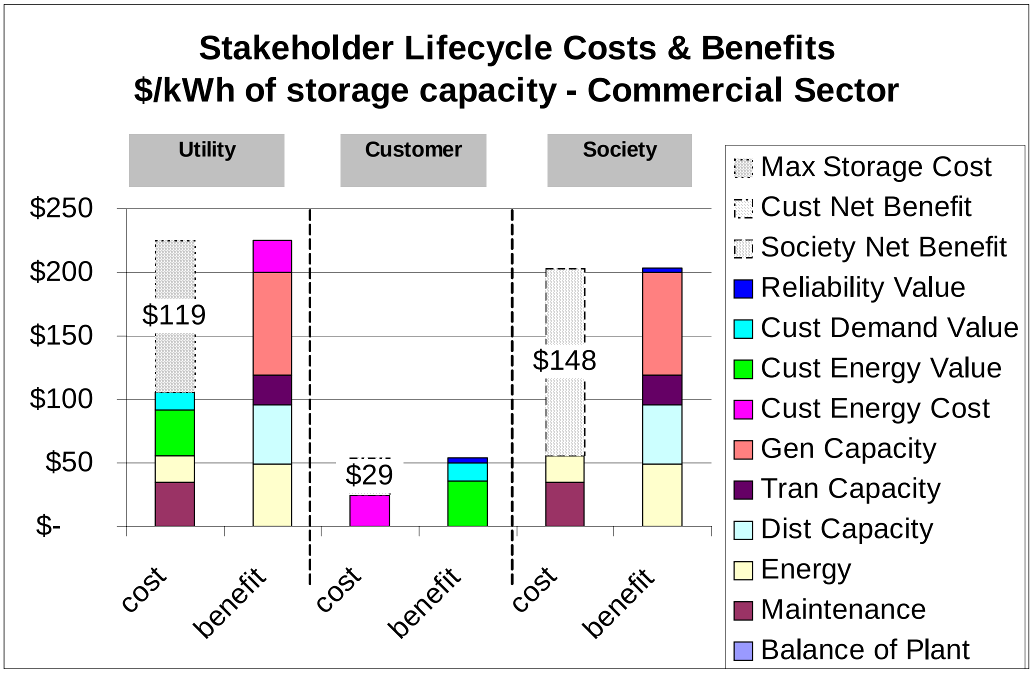

Figure 2-2
Commercial Sector Utility Owned and Dispatched Energy Storage System

This type of analysis is extremely sensitive to the capability of the DESS and estimates of future utility energy and capacity costs. To facilitate a better understanding of the key input parameters in this analysis, a model was utilized[5] which facilitates easy changes to input assumptions and provides sensitivity analysis of key parameters (see Appendix B).

Using base case scenario of a 4 kWh per kW DESS at cost of $148/kWh or $592/kW for a 4 hr system, Figure 2-3 shows the results of the sensitivity analysis from the "social net benefit" perspective and the impact of various changes to the input parameters. In Figure 2-3, the name of the input parameter appears at the bottom of the chart along with the range of base case values of that parameters as well as values corresponding to the high and low values. The base case is also illustrated with the range of break-even storage costs in $ per kWh for each range of inputs.

Parameters are sorted in order of importance. Sensitivity to both DESS performance and drivers of utility cost are included. If a reliability value is assigned to customer at $100/kWh, it becomes the biggest single driver to the customer. The energy/capacity ratio (kWh/kW) of the energy storage system was the second most sensitive parameter. The lower the better for utility applications because one can more precisely target high value hours. Once again, each of these variables is further defined in the Appendix B.

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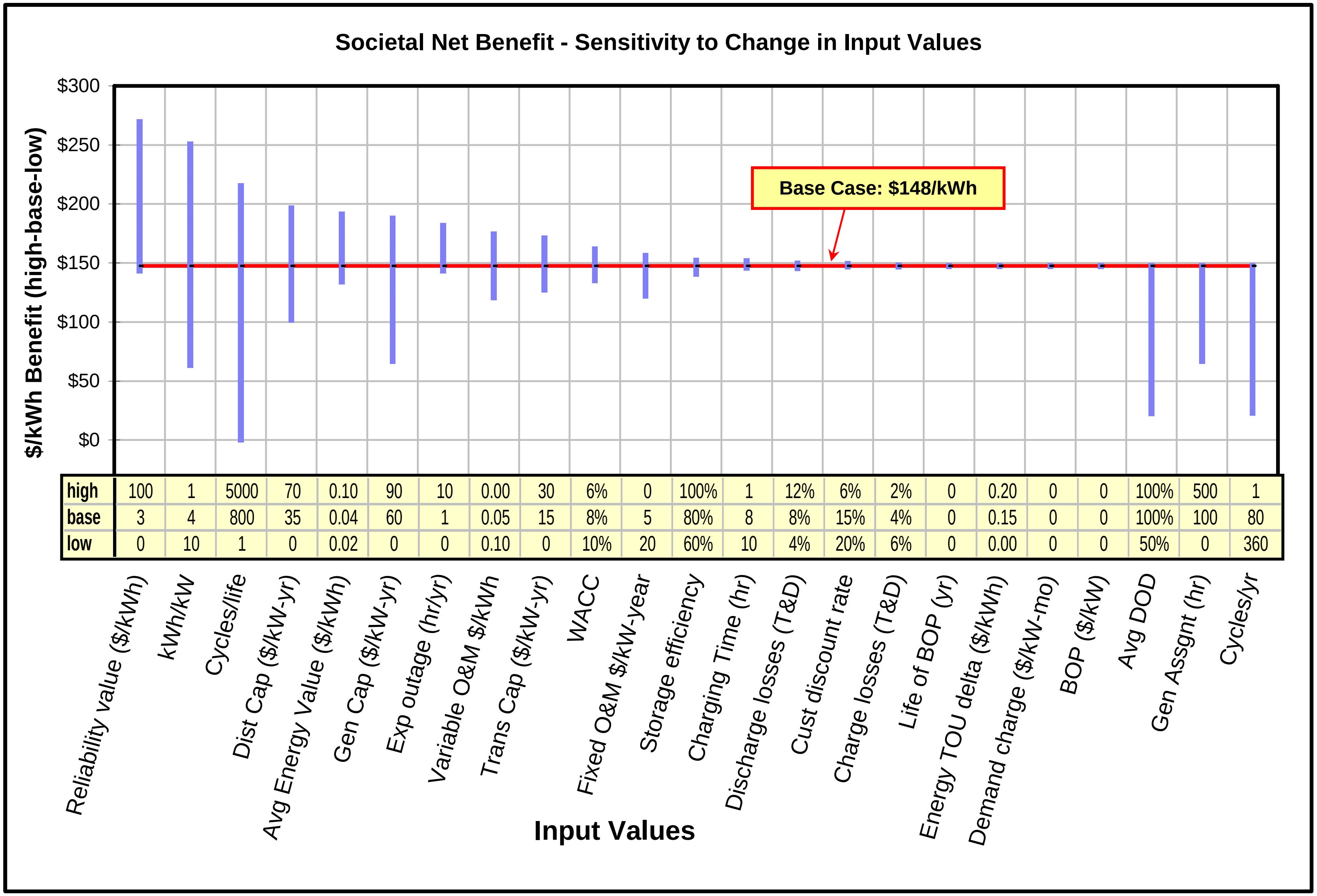
[5] This model has been used by EPRI's Distributed Energy Resources program to estimate the range of cost and benefits of combined heat and power and other types of distributed generation applications. This model was applied to the analysis of distributed energy storage for this project. It continues to be developed and refined in EPRI's energy storage research program area (see Reference 5).



	Reliability value ($/kWh)	kWh/kW	Cycles/life	Dist Cap ($/kW-yr)	Avg Energy Value ($/kWh)	Gen Cap ($/kW-yr)	Exp outage (hr/yr)	Variable O&M $/kWh	Trans Cap ($/kW-yr)	WACC	Fixed O&M $/kW-year	Storage efficiency	Charging Time (hr)	Discharge losses (T&D)	Cust discount rate	Charge losses (T&D)	Life of BOP (yr)	Energy TOU delta ($/kWh)	Demand charge ($/kW-mo)	BOP ($/kW)	Avg DOD	Gen Assgnt (hr)	Cycles/yr
high	100	1	5000	70	0.10	90	10	0.00	30	6%	0	100%	1	12%	6%	2%	0	0.20	0	0	100%	500	1
base	3	4	800	35	0.04	60	1	0.05	15	8%	5	80%	8	8%	15%	4%	0	0.15	0	0	100%	100	80
low	0	10	1	0	0.02	0	0	0.10	0	10%	20	60%	10	4%	20%	6%	0	0.00	0	0	50%	0	360

Figure 2-3
Sensitivity Analysis from Societal Net Benefit Perspective

Discussion

The electric utility-owned and dispatched analysis was performed from the utility, customer and societal perspectives. Some general observations can be made:

- Utility-dispatched applications are cycled relatively few hours per day because high-cost hours on the utility system are on the order of 100-200 hours per year. Thus, this application requires lower duty DESS equipment.
- The study showed that utility owned and dispatched DESS could potentially realize multiple benefits such as T&D capacity, generation capacity and energy values. As shown in the Figures 2-1 and 2-2, the benefit to utilities was $89/kWh and $119/kWh respectively for residential and commercial customers. However, from a customer perspective, the value of DESS was only $58/kWh and $29/kWh. In addition, the primary customer benefit was shown to be reduced energy charges, it could result in utility revenue loss.
- The total societal benefits in these examples were ~ $150/kWh. Utilities could potentially justify a much higher investment in DESS if they could receive an adequate return for delivering the societal values. Customers owning DESS could receive compensation for societal benefits too, but given the historical challenges of monetizing the benefits of end-user owned distributed generation, stakeholders would have to work on an approach that enables the monetization and sharing of distributed storage benefits. This may be more difficult than that in a utility owned business model.
- Across the range of the sensitivity analysis for each of the variables, the societal benefit of the DESS ranged from approximately base case of $148/kWh to as high as $260/kWh ($592/kW to $1040/kW) for a four- hour DESS. It is possible that the benefit could exceed the $260/kWh if benefits for multiple parameters are combined.
- Since the high-cost hours on utility systems are relatively few, utility-dispatched DESS could also be available for customer reliability and backup for other times of the year. Customers who have a high value of reliability might be willing to pay for utility operated and maintained DESS.

End-User Business Model-Customer Owned and Dispatched DESS

Results

The estimated load impacts of the DESS within the service areas of the sample investor owned utilities is shown in Figure 2-4. The percentages of the load impact shown in the figure were calculated based on the aggregated potential storage capacity from each of the utilities divided by their total peak demand (for the residential/commercial sector). It is a function of the cost of the energy storage component. The market potential for residential and small commercial applications was estimated to emerge initially at energy storage component costs of $100/kWh, and reached the load impact of 23% when the cost dropped to $20/kWh.

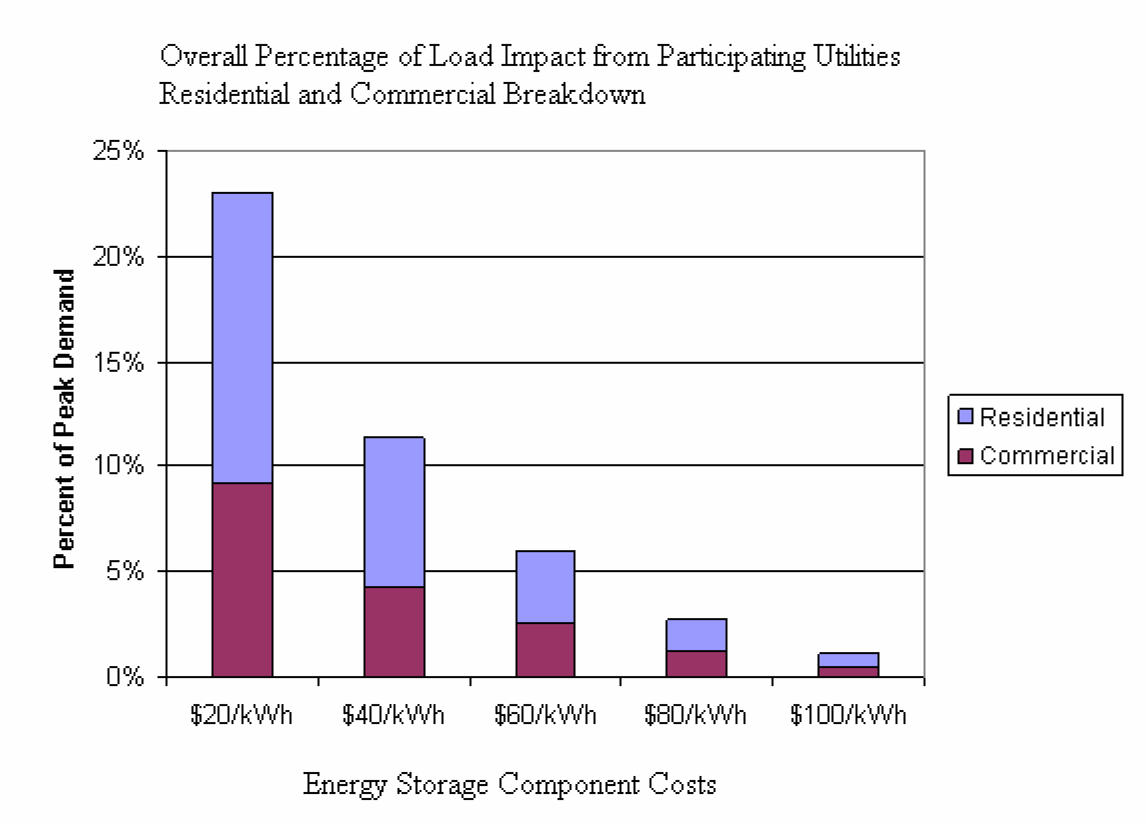


Figure 2-4
Percent Load Impact for Participating Investor Owned Utilities as a function of the Energy Storage Component Costs in $/kWh.

A rough estimate of US market total load impacts was estimated by extrapolating the results presented in the Figure 2-4 for the sample utilities to the national total residential/commercial peak demand. Based on the information from EIA, the US total load was 640 GW in 2004. Multiplying the total US load by the percentages impact shown in the Figure 2-4 resulted in a potential national load impacts between approximately 20 and 150 GWs, if the cost of the energy storage component could fall in the range of $ 80/kWh to $20/kWh, respectively. This is shown in the Table 2-1.

Table 2-1
U.S. Load Impact Extrapolated from Sample Utility Load Impact Analysis

Cost of Energy Storage Component, $/kWh	Sample Utility Load Impact, %	US Total Load, GW	US Extrapolated Load Impact, GW^
80	3	640	19
20	23	640	147

^ estimated by multiplying 640 GW by the percentage of sample utility load impact.

As discussed later in Chapter 3 of this report, current technology is about a factor of 2 to 5 times these cost goals.

The business case for end-use customers and the resulting impact and size for DESS was estimated under an end-user ownership business model where a 3-5 year payback was assumed and an internal rate of return of about 15%. In this case, the DESS must cycle daily in order to provide the necessary payback. The initial cost of inverter/BOP was assumed to range from $200/kW to $400/kW, with residential customers at the high end and larger commercial customers (up to 2 MW of peak demand) at the low end.

The life of the storage system component was assumed to be 1500 cycles before replacement. Results from this base case are shown in Figures 2-5 to 2-8.

Figures 2-5 & 2-6 illustrate results of the average storage size in kWh for residential and commercial building applications respectively as a function of the energy storage component costs in $/kWh.

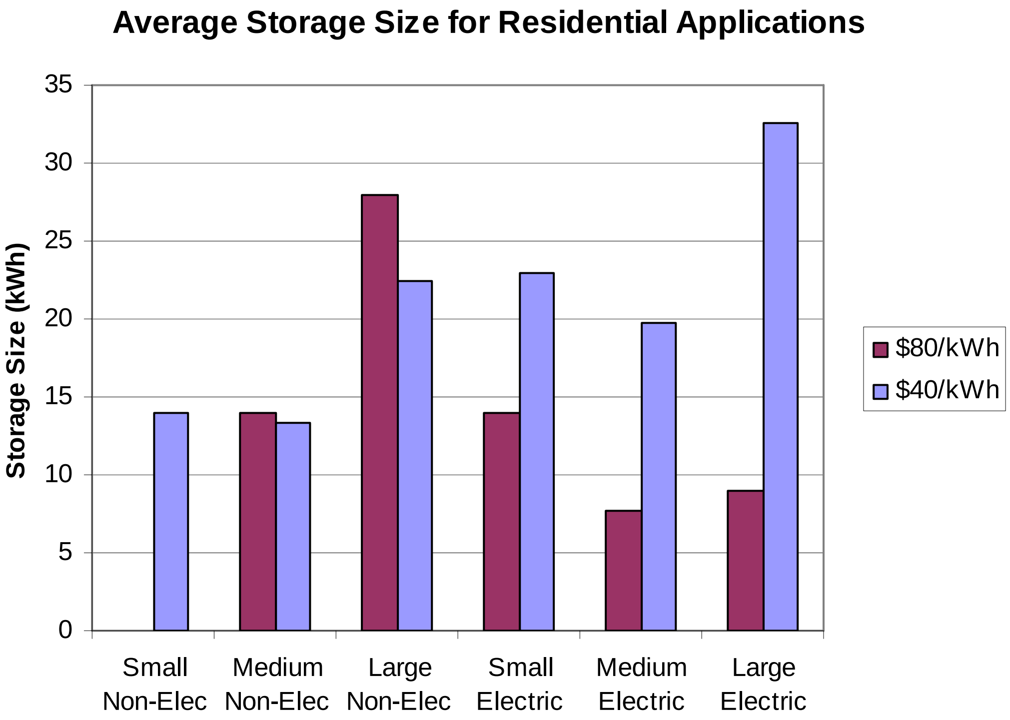


Figure 2-5
Average DESS Size for Residential Application as a function of Energy Storage Component Costs in $/kWh.

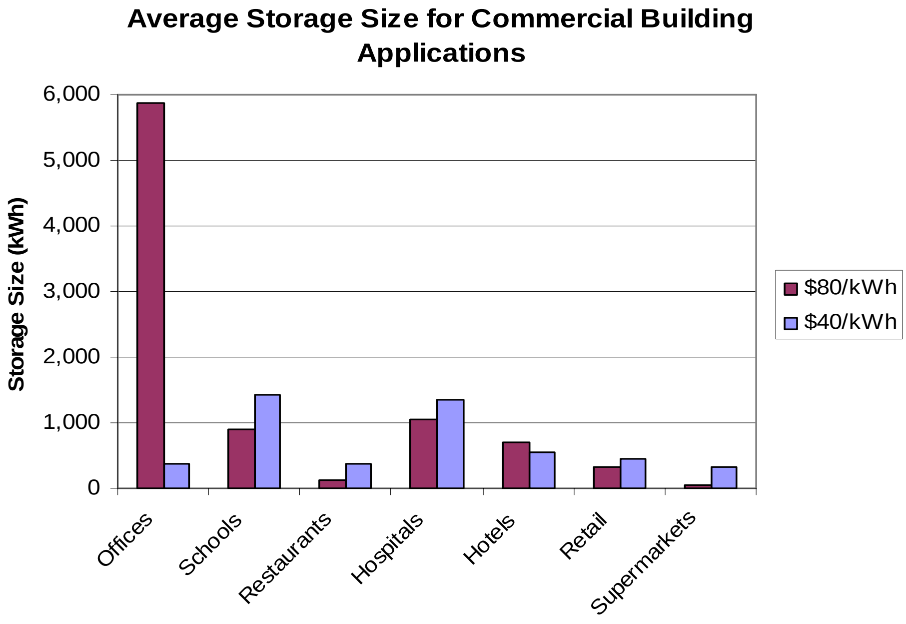


Figure 2-6
Average Energy Storage Size for Commercial Sector Applications as a function of Energy Storage Component Costs in $ /kWh.

Figures 2-6 and 2-7 show the requirements for inverter sizes for residential and commercial market segments based on the needs for an end-user business case.

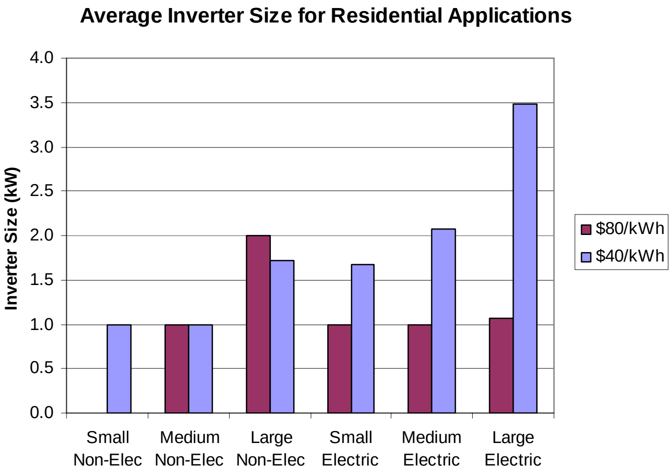


Figure 2-7
Average DESS Inverter Size in kW Estimated for Residential Sector based on End-User Economics as a Function of the Energy Storage Component Costs in $/kWh.

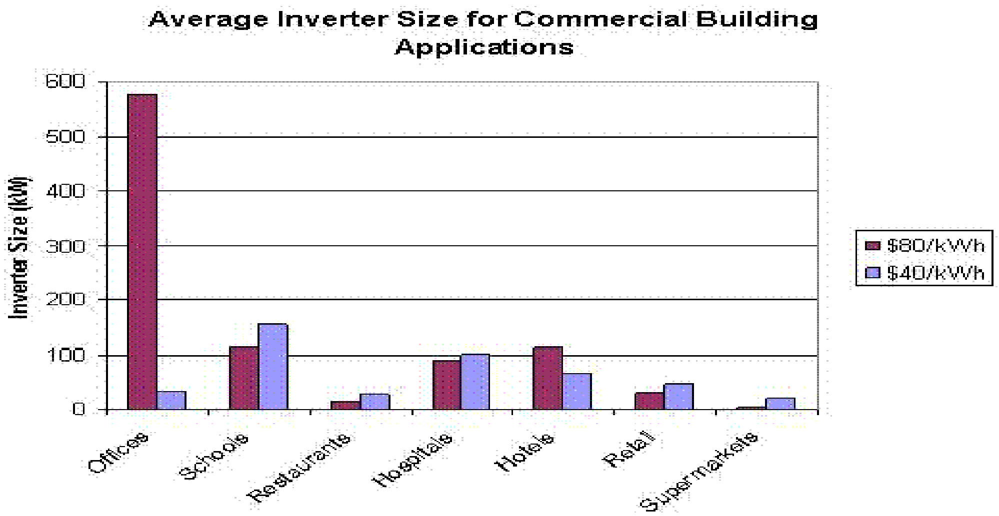


Figure 2-8
Average DESS Inverter Size Estimated for Commercial Building Sector based on End-User Economics as a function of Energy Storage Component Costs in $/kWh.

Discussion

The analysis from the end-user perspective provides insights into the size, technical, operational and economic requirements for small DESS. The observations discussed below are based on a limited sample utility analysis and may not be representative of all regions in the US. Key observations are listed below:

Cost of Energy Storage Component

- At $100/kWh, initial markets emerge, assuming installed BOP cost and cycle life can be attained. The estimated load using DESS at this cost level are ~1%. Applications broaden as energy storage component costs decreases.
- At $60/kWh, the commercial sector starts to emerge, along with a more robust residential sector with the total load levels of just over 5%.
- At $20/kWh, widespread applications were enabled with the total energy storage loads of ~23%.

Size of DESS

- Energy component costs (@$80/kWh) limited DESS applications in the smaller residential houses averaging around 1-2 kW. As this cost reduces (@$40/kWh), medium residential houses become viable candidates at around 3.5 kW. Further cost reduction will allow DESS to penetrate larger houses. Most applications needed increments of 5 kWh. With energy storage component costs at $80/kWh, applications would require 5 to 15 kWh. When energy storage component costs of $40/kWh were assumed, applications required ~ 20-30 kWh. Storage capacities were very dependent on the length of the on-peak period and the size of the inverter, with a 3 kW system and a 5 hour on-peak period generally requiring 15 kWh of storage.

- Commercial segment applications require different sizing for different customers, but average between 30kW for retail and restaurant customers to around 100-150 kW for schools, hotels and hospitals. The average storage capacity for majority of the applications averages between 100 kWh to 1,500 kWh. Therefore, most of the commercial applications could be economically sized in increments of 50 kW/100 kWh.

Cycle Life

- Commercial applications were well suited to 1500 cycles, and that the market potential dropped off if life reduced from 1500 to 500 cycles. The base case market potential at 1500 cycles dropped by two-thirds when cycle life was reduced to 500 cycles. Similarly, end-use residential applications also dropped off significantly from 1500 to 500 cycles (a drop of over 80 percent). Residential applications showed marked improvement with a 3000 cycle life system, over doubling the market size.

On-Peak and Off-Peak Costs

- End-use commercial applications require differences between On-Peak and Off-Peak demand charges**.** Commercial applications tend to offer better economics with shorter on-peak periods since the bill savings are based on demand reduction and not in reducing energy charges. In the commercial sector, once the demand charge bill savings have been realized there is no further benefit in operating the energy storage system. This was not the case in the residential sector where in most cases the demand charge costs are imbedded into the average $/kWh rate.
- Residential applications require a significant differential between On-Peak and Off-Peak energy charges on the order of 10-20 cents per kWh for economic viability.

Drivers for Adoption

- This analysis was based on the primary driver being annual bill savings and the ability of the energy storage system to provide a 3-5 year payback. The analysis was based on present utility rates.
- Customers who value reliability may be potential early adopters**.** Sensitivity analysis revealed that if a customer places a $200/kW annual value on avoided outages, the cost of the energy storage component becomes mostly irrelevant, at least up to $100/kWh.

3
SUMMARY

The market driven energy storage requirements estimated in this study are aggressive and unattainable today given the current status and costs of DESS. Table 3-1 illustrates examples of the costs and features of currently available energy storage technologies. The reader also should turn to the references in Appendix A for more details on the current status and trends in energy storage systems. Current technology costs are from 2 to 5 times the market penetration requirements described in this analysis.

Table 3-2 provides an overall summary of the results and perspectives from utility owned and customer owned applications.

The study findings suggest a path way of adoption for DESS could be through electric utilities. Utilities could use DESS to manage load and operation of the distribution system. The range of allowable cost for these types of applications should be reached much earlier than the allowable cost range for end-use customers to justify and adopt energy storage on a widespread basis. As a result, the utility could be an early adopter of energy storage systems.

The results presented in this report were derived from a limited sample of investor utility data and may not be entirely representative of the entire US market. These results may also not represent the market needs in the rural or municipal utility sectors. The analysis of the value of distributed storage can also be very system and site specific. This study did not examine the cost and value for other applications involving distribution system and network support, asset management or in applications with renewable power systems. Follow on research is needed to assess the market requirements for those applications with other industry stakeholders.

This assessment, however, helps in the understanding of some of the technical and economic parameters related to DESS. Several key attributes for such systems were developed from this assessment to help stakeholders including storage manufacturers, system integrators, energy service companies, electric distribution companies and other utilities move towards solutions that could take hold in the marketplace.

To continue to advance the engagement of stakeholders in helping shape a “market pull” for distributed energy storage systems, EPRI initiated a new initiative in early 2006 as a follow-on from the work reported here. See Appendix D for supplemental information on EPRI’s continuation project to advance break through and innovation in distributed energy storage systems that expect to bring value to the electric enterprise.

Table 3-1
Examples of current and projected battery energy storage systems

Technology	Life	Cost \$/kWh[a]	Competitive Intensity	Strengths and Weaknesses
Lead Acid Pb-Acid	5-20 yrs, limited cycles	200- 300	High	"Low" cost option for UPS and telecom applications, life sensitive to operating temperatures, limited deep cycle life, mature technology
Nickel Cadmium NiCd	15-20 years Cycles >1000	500 - 600	High	Robust technology, long life, high power for UPS and telecom, high cost, mature technology
Sodium Sulfur NaS	>10 years >2600 cycles	300-500 (b)	Low	Single developer, near commercialization, high temperature battery, developed for stationary markets
Sodium Nickel Chloride $NaNiCl_2$ "ZEBRA"	>10 years >2600 cycles	TBD <200	Low	Single developer, near commercialization, high temperature battery, developed for EVs and HEVs, some stationary prototypes
Flow Batteries	Long life claimed	TBD	Low	Under development since 1980's by small companies for stationary applications
Nickel metal hydride NiMH	10 years 1300 cycles	>650 (c)	High	Cycle number from Cobasys for 80% DOD, battery now in HEVs, High cost, temperature sensitive
Lithium ion Li-ion	>10 yrs >2,000 cycles	>650 (c)	High	High energy density, high power, can demand premium prices, increasing market share and number of applications

a) Pb-Acid, NiCd and ZEBRA are estimated OEM battery costs. b) NaS costs shown are estimated for a fully installed and integrated 1 MW / 7 hr system. See References 1, 2, and 3. c) The cost of typical NiMH and Li-ion cells are listed at greater than \$650, however prices of commodity Li-ion cells to OEMs have dropped to around \$250/kWh; NiMH and Li-ion costs will vary with performance of the product and the target application, however, current costs are generally much greater than the targets for stationary applications.

Table 3-2
Summary of the Results

	Utility Owned and Dispatched DESS	**Customer Owned and Dispatched DESS**
Benefits	T&D support Load shifting & load management Generation capacity values Ability to site, operate & maintain Clean and quiet operation Ability to monetize societal benefits via ratemaking Potentially shorter sales and adoption period Long regulated payback potentially possible	Bill savings Reliability, back-up power Less capital outlay Clean and quiet operation
Potential Issues	Regulatory approval Management of large number of aggregated assets Communication and control linkage with utility SCADA	Long payback Difficult to monetize societal benefits Long sales and adoption period Transaction cost for sales is high per unit
Value of DESS Note: Current technology is about a factor of 2 to 5 times this cost goal.	Societal value: ~ $592 to $1040 per kW installed for a 4 hr system. Utility: $ 360 to $ 480 per kW for 4 hr systems	Societal value[6] ~ $592 to $1040 per kW installed for a 4 hr system. Commercial Sectors: $120-$ 240 per kW Residential Sector: - $ 640 /kW niche markets - $ 480 / kW mass markets (for 4 hr systems)
Cycles/yr	80	~ 260
DESS Size	Commercial Sector 30-150 kW Residential Sector 1-5 kW	Commercial Sector: 30-150 kW Residential Sector: 1-5 kW

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[6] Societal values may be difficult to monetize

A
REFERENCES

1. Comparison of Storage Technology for Distributed Resource Applications, EPRI Report 1007301, 2003
2. EPRI- DOE Handbook of Energy Storage for Transmission and Distribution Applications, EPRI Report 1001834, 2003
3. Technology Review and Assessment of Distributed Energy Resources. Distributed Energy Storage, EPRI report 1012983, 2005
4. Economic Costs and Benefits of Distributed Energy Resources, EPRI Report 1011305, December 2004.
5. Energy Storage Valuation Tool: Modeling Stakeholder Costs and Benefits, EPRI Software 1014595, November 2006.

B

DEFINITION OF TERMS

This Appendix provides a definition of terms and discussion of input parameters used to develop the analysis from the electric system perspective as discussed in the Results Section. This Appendix also provides the proxy's for the inputs including the base case and for ranges of high and low values around the base case.

Utility-side inputs

Value	Inputs	Base Case	High	Low	%	Base Case %
$ 35.00	**Distribution Capacity $ per kW-year**	35	70	0	50	50

This input assigns the value of distribution capacity on the T&D system. In the model, dispatch of energy storage provides a distribution capacity benefit to the utility that is proportional to the value of this input. The default base case value is $35 per kilowatt-year.

Value	Inputs	Base Case	High	Low	%	Base Case %
$ 15.00	**Transmission Capacity, $ per kW-yr**	15	30	0	50	50

This input assigns the value of transmission capacity on the T&D system. In the model, dispatch of energy storage provides a transmission capacity benefit to the utility that is proportional to the value of this input. The default base case value is $15 per kilowatt-year.

Value	Inputs	Base Case	High	Low	%	Base Case %
$ 60.00	**Generation Capacity, $ per kW-yr**	60	90	0	67	67

This input assigns the value of generation capacity on the T&D system. In the model, dispatch of energy storage provides a generation capacity benefit to the utility that is proportional to the value of this input. The default base case value is $60 per kilowatt-year.

Value	Inputs	Base Case	High	Low	%	Base Case %
100	**Gen value assignment (hours/yr**)	100	500	0	20	20

This input determines the number of hours per year to which generation capacity value is assigned. The generation capacity value is divided equally among these hours, and all other hours are considered to have zero capacity value. The hours chosen are those with the highest cost of energy supply during the 8760 hours of the year. Energy storage dispatch during one of these hours will capture the generation capacity value for that hour. The default setting assigns the generation capacity value for the base case to the top 100 hours.

Value	Inputs	Base Case	High	Low	%	Base Case %
$ 0.04	**Average Energy Value $ per kWh**	0.04	0.10	0.02	25	25

This input states the average cost of energy to the utility over the entire year. In the model, the average cost of energy is multiplied by an hourly price-shape factor for each hour of the year to give the actual cost of energy in that hour. The default average energy value for the base case is $0.04 per kilowatt hour. The default slider bar range is $0.02-0.10 per kilowatt hour.

Value	Inputs	Base Case	High	Low	%	Base Case %
1	**kW active capacity**	1	1	1	50	50

This parameter determines that the model outputs will be calculated per kilowatt of discharge capacity of the energy storage system.

Value	Inputs	Base Case	High	Low	%	Base Case %
8	**charging time (hours**)	8	10	1	78	78

This input determines the length of time required for the energy storage device to charge. That model assumes that the device is fully discharged during each discharge, then fully charged during each charging period. Charging is assumed to be linear, in other words that an equal amount of energy must be used for charging in each hour that charging occurs. The default base case value is 8 hours. The default slider bar range is 1-10 hours.

Value	Inputs	Base Case	High	Low	%	Base Case %
4	**kWh/kW active storage**	4	10	1	33	33

This input assigns the amount of energy storage capacity in kilowatt hours for each kW of discharge capacity. The default value for the base case is 4, meaning that for each 1 kW of power that the energy storage system can supply (e.g. through its inverter), it has 4 kilowatt hours of storage capacity (e.g. in its batteries). This also means that the system will discharge for 4 hours (e.g. 4 kilowatt hours divided by 1 kW). The default slider bar range is 1-10 kWh/kW.

Value	Inputs	Base Case	High	Low	%	Base Case %
800	**cycles/life**	800	5000	1	16	16

This input assigns the total length of the storage device’s life in terms of the number of charge/discharge cycles. The default base case value is 800 cycles.

Value	Inputs	Base Case	High	Low	%	Base Case %
80	**cycles/yr**	80	365	1	22	22

This input determines the number of charge/discharge cycles that the energy storage devices are to be operated per year. The default base case value is 80 cycles, meaning that the storage device will be utilized 80 times over the course of the year. The length of time the device will charge and discharge during each cycle is determined by the charging time and kWh/kW inputs above. The default slider bar range is 1-365 cycles per year.

Value	Inputs	Base Case	High	Low	%	Base Case %
20	**maximum storage life (years)**	20	20	1	100	100

This input places an upper limit on the physical lifetime of the energy storage device, independent of the number of cycles it is operated. In the default base case, the device cannot remain in operation more than 20 years, even if it has not utilized its entire cycle life.

Value	Inputs	Base Case	High	Low	%	Base Case %
100%	**average depth of discharge (DOD)**	100%	100%	50%	100	100

This input determines how much of the energy storage capacity is used in each discharge. The default base case value is 100%, meaning that the entire storage capacity is utilized. The default slider bar range is 50-100%. Comment: In real batteries, the cycle life is related to the average depth of discharge. This effect is not reflected in the present model, in which the cycle life is set independently by the user. What the average depth of discharge does affect is the total storage requirement of the system. For example, if the average depth of discharge is 80%, the model assumes that 1.25 kWh of actual storage capacity is required for each 1.0 kWh of storage capacity that is charged and discharged (the "active" capacity).

Value	Inputs	Base Case	High	Low	%	Base Case %
80%	**charge & discharge efficiency, Percent**	0.8	1	0.6	50	50

This input specifies the "round-trip" efficiency of the energy storage system, meaning the useful output of the system given both charging and discharging losses within the system at the customer site. This value is completely separate from losses in the utility's T&D system, which is set in the inputs below. The default base case value is 80%. The default slider bar range is 60-100%. Comment: The round-trip efficiency, together with the charging losses on the T&D system, determine how many kWh from the utility system are required to provide 1 kWh discharged from the energy storage system into the utility system.

Value	Inputs	Base Case	High	Low	%	Base Case %
4.0%	**charge losses, Percent**	0.04	0.06	0.02	50	50

This input specifies the average losses in the T&D system at the time when the energy storage system is charged. The default base case value is 4%. The default slider bar range is 2-6%. As an example, if 1 kWh is delivered to the energy storage system (prior to round-trip efficiency losses within the storage system itself), then in the default base case, 1.04 kWh must be delivered by the utility to the T&D system.

Value	Inputs	Base Case	High	Low	%	Base Case %
8.0%	**discharge losses, Percent**	0.08	0.12	0.04	50	50

This input specifies the average losses in the T&D system at the time when the energy storage system is discharged The default base case value is 8%. The default slider bar range is 4-12%. This input value increases the energy value to the utility of the discharge by the energy storage system. For example, in the default base case, if the energy storage system delivers 1 kWh to the utility T&D system, it effectively displaces 1.08 kWh when the avoided T&D discharge losses are taken into account. Comment: In the default case, T&D charging losses have been set lower than the discharge losses to reflect the fact that charging will generally occur at off-peak hours, and discharge at on-peak hours, with T&D loading being higher during on-peak hours.

Value	Inputs	Base Case	High	Low	%	Base Case %
0	**Balance of Plant ($/kW)**	0	0	0	0	0

This input is disabled in the current configuration of the model, which calculates the maximum allowable value of the entire installed energy storage system (i.e. both storage and balance of plant).

Value	Inputs	Base Case	High	Low	%	Base Case %
0.05	**O&M $/kWh**	0.05	0.1	0	50	50

This input specifies the variable operation and maintenance cost per kilowatt hour of energy discharged into the utility T&D system by the energy storage system. The default base case value is $0.05 per kilowatt hour.

Value	Inputs	Base Case	High	Low	%	Base Case %
5	**O&M $/kW-year**	5	20	0	25	25

This input specifies the fixed operation and maintenance cost per kilowatt of discharge capacity of the energy storage system. The default base case value is $5 per kilowatt-year.

Value	Inputs	Base Case	High	Low	%	Base Case %
$ 0.15	**dispatch threshold (if not same day)**	0.15	1	0	15	15

This input specifies the minimum supply cost differential that must be met for same-day dispatch to occur. This input is disabled in the current model configuration.

FALSE	**Customer Dispatch**	FALSE				

This input check box changes the dispatch algorithm in the model from the default value, which optimizes utility value by dispatching the energy storage system at the times of highest value for the 8760 hour price shape, which is in turn based on California utility proxy data. By checking the check box, a new algorithm is used that dispatches the energy storage system to maximize customer value. The dispatch algorithm for this option uses the California proxy data for supply cost.

Value	Inputs	Base Case	High	Low	%	Base Case %
8.00%	**WACC, Percent**	0.08	0.1	0.06	50	50

This input specifies the weighted-average cost of capital to the utility. It is used in the financial calculations of the allowable energy system cost for the default case, in which the energy storage system is owned by the utility and discharged to maximize utility benefit. The default base case value is 8%.

10	**life of storage device (years)**					

The life of the storage device in years is a calculated output equal to the cycles/life divided by cycles/year, but capped at the maximum storage life. In the default base case, the energy storage device is assigned a cycle life of 800 cycles, and is operated 80 cycles per year, resulting in a 10 year life.

Value	Inputs	Base Case	High	Low	%	Base Case %
0	**life of BOP (years)**	0	0	0	0	0

This input is disabled in the current configuration of the model, which treats the entire energy storage system (i.e. both storage and balance of plant) as a single unit.

320	**kWh / year actual dispatch**					

This value is an output. The kilowatt hours per year dispatched by the energy storage system is the product cycles per year times kWh/kW (these inputs are explained above). The resulting value is per 1 kW of discharge capacity.

1.00	**kW nominal capacity**					

This value is equal to the kW of active capacity in this configuration of the model. It should have a value of 1.0 in all cases.

4.00	**kWh nominal storage**					

This value is an output. The kilowatt hours of nominal storage is determined by the kWh/kw divided by the average depth of discharge of the storage device. The resulting value is per 1 kW of discharge capacity. Comment: Nominal storage is the storage capacity that is purchased and maintained by the utility or the customer. Financial calculations related to storage capacity are based on this value, whereas energy calculations are based on the "active" value.

15%	**annualization factor for storage**					

This value is an output. Annualization factor is a function of the WACC and the energy storage system lifetime.

6.71	**PW factor for storage**					

This value is an output. Present worth factor is the inverse of the annualization factor.

Customer-side inputs

Value	Inputs	Base Case	High	Low	%	Base Case %
$ 0.150	**energy delta (on-peak minus off) $ per kWh**	0.150	0.20	0	75	75

This input specifies the difference between the on-peak and off-peak price of energy seen by the customer. The default base case value is $0.15 per kilowatt hour. The default slider bar range is $0-0.20 per kilowatt hour. Comment: The value of energy storage dispatch to the customer is proportional to this value. The higher the time-of-use differential, the higher the customer benefit, all other things being equal. A flat-rate tariff provides no value of energy storage dispatch for the customer, although there may be a reliability value for the customer if the system is configured to operate in stand-alone mode in the case of an outage.

Value	Inputs	Base Case	High	Low	%	Base Case %
$ 0.050	**off-peak energy ($/kWh)**	0.050	0.25	0	20	20

This input specifies the off-peak price of energy seen by the customer. The default base-case value is $0.05 per kilowatt-hour.

Value	Inputs	Base Case	High	Low	%	Base

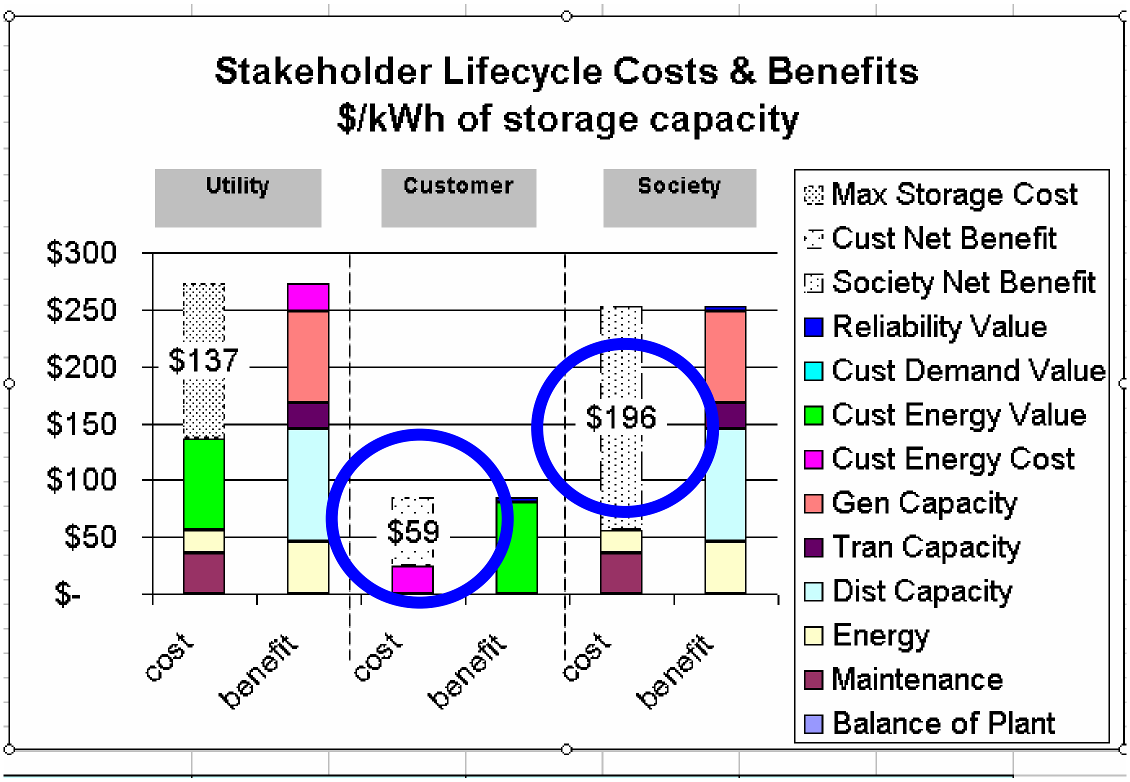
						Case %
$ 0	**demand charge ($/kW-mo)**	0	20	0	0	0
This input specifies the demand charge seen by the customer. The default base-case value is $0 per kilowatt-month. The default slider bar range is $0-20 per kilowatt-month. (The default base case assumes a residential customer with no demand charge.) Comment: In the current configuration of the model, the customer's avoided demand charge due to dispatch of the energy storage device is linearly proportional to the number of discharge cycles, up to the maximum number of days per year with differential between on-peak and off-peak energy values.						
Value	Inputs	Base Case	High	Low	%	Base Case %
$ 3	**reliability value ($/kWh)**	3	100	0	3	3
This input specifies the customer's value of service. It represents the avoided customer losses in the case of a forced outage, and assumes that the energy storage system is configured to operate in stand-alone mode in the case of an outage. The default base-case value is $3 per kilowatt hour.						
Value	Inputs	Base Case	High	Low	%	Base Case %
1.0	**expected outage hours per year, hours**	1	10	0	10	10
This input specifies the expected number of forced outages faced by the customer per year. The total reliability value is the product of the reliability value above times the expected outage hours. The default base-case value is 1 hour per year.						

Value	Inputs	Base Case	High	Low	%	Base Case %
255	**max cycles/yr**	255	365	1	70	70
This input specifies the maximum number of days per year with a positive differential between on-peak and off-peak energy values. This is the maximum number of cycles that it is rational to discharge the energy storage device. The customer's avoided demand charge is proportional to the actual number of dispatch cycles divided by the maximum cycles per year. The default base case value is 255 cycles.						
Value	Inputs	Base Case	High	Low	%	Base Case %
15%	**customer discount rate, Percent**	0.15	0.20	0.06	64	64
This input assigns the customer discount rate. This rate is used in the customer-side financial calculations of the value of energy storage. The default base-case value is 15%.						
4	kWh/kW (same as utility)					
This output value is identical to the utility value explained above.						
80%	efficiency (same as utility)					
This output value is identical to the utility value explained above.						
80	actual cycles (same as utility)					
This output value is identical to the utility value explained above.						
5.02	customer PW factor					

This output is determined by the customer discount rate and the lifetime of the energy storage system.

Energy storage model outputs

Model outputs are shown and displayed as a stacked chart. The Stakeholder stack chart calculates the allowable cost and value of energy storage system



The stakeholder stack chart shows the total and individual costs and benefits from each of three stakeholder perspectives: (1) utility, (2) customer, and (3) society. In the case of the customer and society perspectives, total benefits are subtracted from total costs to give a net benefit (see blue circles). In this example stacked chart case of the utility, which is assumed to own the energy storage system, all costs except for the energy storage system itself are subtracted from the total benefits. The result gives the maximum lifecycle cost of the energy storage system that allows the utility to break even, in dollars per kilowatt hour of storage capacity (see red circle there is no red circle). In the example case pictured above, the maximum amount that can be paid cost-effectively by the utility is $137/kWh.

Note that in this case, the societal net benefit is $196/kWh. This can be seen as representing the maximum allowable cost of the energy storage system from society's perspective.

The individual model outputs are described below.

Model outputs: lifecycle stakeholder costs and benefits

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Balance of Plant	$ -	$ -	$ -	$ -	$ -	$ -

In the current configuration of the model, balance of plant is included in the cost of the energy storage system. Therefore, the value of balance of plant is zero throughout.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Maintenance	$ 35	$ -	$ -	$ -	$ 35	$ -

Maintenance cost is derived from the cycles and output of the energy storage system, and from the user-assigned variable and fixed O&M costs inputs (see above). Since the energy storage system is assumed to belong to the utility, maintenance cost appears in the utility cost column. It also appears as a societal cost.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Energy	$ 21	$ 49	$ -	$ -	$ 21	$ 49

Energy has two components. (1) The energy cost to the utility of charging the energy storage device, based on the hourly energy supply costs and loss factors during the charging hours. (3) The energy benefit to the utility of discharging the energy storage device, based on the hourly avoided costs of supply including loss factors during the discharge hours. These costs and benefits also appear in the societal column.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Dist Capacity	$ -	$ 47	$ -	$ -	$ -	$ 47

Distribution capacity value is the value to the utility of avoided use of the distribution system due to dispatch of the energy storage device. This appears as a benefit to the utility and to society.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Tran Capacity	$ -	$ 23	$ -	$ -	$ -	$ 23

Transmission capacity value is the value to the utility of avoided use of the transmission system due to dispatch of the energy storage device. This appears as a benefit to the utility and to society.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Gen Capacity	$ -	$ 81	$ -	$ -	$ -	$ 81

Generation capacity value is the value to the utility of avoided use of generation capacity due to dispatch of the energy storage device. This appears as a benefit to the utility and to society.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Customer Energy Cost	$ -	$ 25	$ 25	$ -	$ -	$ -

Customer energy cost is the amount paid by the customer at the prevailing price per kilowatt hour during the hours in which the energy storage device is charged. It appears as a customer cost and a utility benefit, which results in zero net value from society’s perspective.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Customer Energy Value	$ 80	$ -	$ -	$ 80	$ -	$ -

Customer energy value is the amount not paid by the customer to the utility during the hours in which the energy storage device is dispatched, based on the prevailing price per kilowatt hour during those hours. It appears as a customer benefit and a utility cost, which results in zero net value from society’s perspective.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Customer Demand Value	$ -	$ -	$ -	$ -	$ -	$ -

Customer demand value is the amount not paid by the customer to the utility during the hours in which the energy storage device is dispatched, based on the percentage of peak demand avoided. (See the explanation of the demand value input parameter above for further information). It appears as a customer benefit and a utility cost, which results in zero net value from society’s perspective. In the residential case shown here, demand charges were set to zero, therefore no demand charge appears.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Reliability Value	$ -	$ -	$ -	$ 4	$ -	$ 4

Reliability value is the benefit to customers from avoided loss of service. It also appears as a benefit to society.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Max Storage Value, $ per kWh	$ 89	$ -	$ -	$ -	$ -	$ -

Maximum storage value is the net of utility benefits and all costs other than the energy storage system. The result is the maximum allowable cost of energy storage (including balance of plant in this configuration of the model) for which the utility can break even. This result is the principal output of the model.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Customer Net Benefit	$ -	$ -	$ 59	$ -	$ -	$ -

Customer net benefit is the net of all customer benefits and costs.

	Utility		Customer		Society	
	cost	benefit	cost	benefit	cost	benefit
Society Net Benefit, $ per kWh	$ -	$ -	$ -	$ -	$ 148	$ -

Society net benefit is the net of all societal benefits and costs, which is the sum total of the utility and customer benefits and costs. As mentioned above, this can also be seen as representing the maximum allowable cost of the energy storage system from society's perspective.

See Reference 5 for updated documentation to this model.

C
END-USER ANALYSIS ASSUMPTIONS

The table below provides a listing of the key assumptions made to perform the end-user analysis.

Storage System		**Key Assumptions**
Overall Electricity Storage System		• Located outdoors in enclosure that would be acceptable in a residential community • Total of balance of plant ($/kW) and storage ($/kWh) represented all installed costs • System efficiency, assumed to be 75 %, is defined as: $\frac{\text{(electricity input into storage system)}}{\text{(110/220 volt electricity output from system)}}$ • System efficiency includes any parasitic electricity to heat/cool within the enclosure • Ratio of kWh/kW is used to calculate actual battery capacity of system. Under one full discharge, the kWh/kW ratio multiplied by the kW of the system represents the actual energy the system delivers at 110/220 volts during a full discharge down to the maximum discharge level (a 4 kW with a 7 kWh/kW ratio can deliver 28 kWh at 110/220 volts during one full discharge when discharged over 5-14 hours)
System Cost	**Cost of all balance of plant, not including storage, in $/kW power delivered**	<u>Charger</u> • Charger is able to fully charge battery in 10 hours, and also programmable to charge over longer durations (up to 72 hours), if required, without a drop in efficiency <u>Inverter/Power Conditioning System</u> • kW represents maximum continuous power output of system at 110/220 volts • Utility grade power (voltage levels and ranges, voltage balance, harmonic distortion, voltage fluctuation and flicker, voltage disturbances, stray voltage, and voltage frequency) • System to operate in parallel with grid, so high, short-duration peak output to start motors is not required <u>Interconnection system</u> • Parallels with the grid • Automatic dispatch – ability to program charge/discharge times • IEEE 1547 compliant <u>Balance of Plant</u> • All of equipment needed for a completely installed system, including delivery, site-preparation, and any other soft costs • All equipment other than energy storage component; maintenance assumed to have a service life of 20 years

	Cost of energy storage subsystem, in $/kWh delivered	• kWh represents energy delivered when discharging the battery from full charge down to the maximum discharge level • Discharge period is 5-14 hours and the batteries must deliver the rated kWh when continuously discharged over 5-14 hours • Storage capacity per full discharge does not fall below this level over life of battery as the battery ages • Storage capacity per full discharge does not fall below this level between 0-100 °F, or at a temperature range controlled by the enclosure
Battery Life		• One cycle is fully charging the system and then discharging the system down to the maximum discharge level • Partial discharges count as a fraction of a full discharge, and not as a full discharge • Within its cycle life, counting all full discharges as well as adding partial discharges, battery will be capable of discharging its full capacity
Financial Parameters		• Project Length (years) 20 • Federal Income Tax (%) 35 • State Income Tax (%) 5 • Property Tax and Insurance (%) 2 • Internal rate of return, % 15 •
Electric Rates		Time of use rates from sample utilities

D

SHAPING MARKET PULL FOR DISTRIBUTED ENERGY STORAGE: APPLICATIONS, SPECIFICATIONS, AND PRIORITIES

Introduction

A two day workshop was held at the Electric Power Research Institute on July 25th and 26th 2006 to start a process to accelerate innovation towards the development of commercial electric storage systems of value to the electric power industry. Forty (40) participants including electric utilities, vendors, systems integrators and researchers met at EPRI. Table D-1 lists the participants

This Appendix provides a summary from EPRI's Technology Innovation project to pilot a new process in the area of science of discovery, invention, creative problem solving, and innovation. One of the unique features of the EPRI initiative is the desire to couple tightly the needs of users (utilities) and the demands of the market with the flash and spirit of invention ("technology push"). A second unique feature is the Project's "open source" architecture. In other words, the breakthroughs we seek in distributed storage are of sufficient general and public importance, the participants are willing to contribute their ideas freely to advance the common good. The project will seed a "Collaborative Network" of key stakeholders to drive solutions to key barriers in distributed energy storage. Below is a summary of the key inputs, discussions and findings from this workshop

Table D-1 Stakeholders attending the EPRI Workshop July 25th and 26th 2006

ABB
American Electric Power
Arizona Public Service
ElectroEnergy, Inc.
EPRI
EPRI Solutions
Gaia Power Technologies
Maxwell Technologies
SRI International
PG&E
Premium Power
San Diego Gas & Electric
VRB Power Systems
GE Global Research
Technology Insights
City of Palo Alto Municipal Electric
ZBB Energy
Electricity de France
Southern California Edison
SAFT
FirstEnergy
Technology Insights, Inc
Public Service Electric & Gas
Southern Co

Imagineering the Grid of the Future

The participants were first asked to brainstorm what the electric grid in 2015 might look like and to identify the relevance and roles for distributed energy storage systems (ES) in that future grid. Below is a summary of the discussion points:

1. Optimal integration of central and distributed power; co location of heat and power; flexible power and fuels; energy storage plays into the grid; closer to the loads where energy is utilized; ES enables optional use of grid assets
2. Storage units area like HVAC in a home
3. Small communities, or micro-grids generate their own power; local entities in control of their power and reliability needs
4. Grid enables simple choices for customers; allows for different levels of reliability; ES helps provide energy service and delivery choices
5. Energy Parks with larger ES systems
6. Manufactures integrate ES into appliances; software to control/dispatch
7. Plug-in hybrids enable mobile energy storage
8. Transportable ES (2-3 MW) to support grid during peak times.
9. More portable energy storage is everywhere
10. A smart grid so intelligent there will be no need for energy storage
11. Multiple types of ES for different applications
12. UPS systems at customer sites so advanced they can be dispatched by the grid operators
13. Current standby back-up generators are replaced by dispatchable energy storage systems

Prioritization of Most Important Applications

Three teams were assembled and participated in break-out sessions to discuss and rank their most important applications for distributed energy storage. Each team reported back their discussions and the entire group then voted to rank the applications of distributed energy storage of most interest. The results are summarized below (# votes):

1. Reliability of service Asset utilization (9)
2. Optimization of Existing Assets (6)
3. Load Mgmt/Peak Shaving / Demand Response (5)
4. Renewable – arbitrage, peak shifting (2)
5. Renewables (PV & Wind) (1)
6. Plug-in Hybrids (3)

However, given the ranking of the specific applications of most interest there still needs to be continued work and discussion in framing the duty, mission, and solution the energy storage option is providing in each of these applications. This was explored somewhat in the next session below under target specifications.

Target Specifications for Key Applications

Teams were assembled and participated in break-out sessions to discuss the key technical and performance requirements and barriers for the applications ranked above. Each team reported back their discussions. The results are summarized below:

1. **Panel 1: Reliability / Asset Utilization /Utility Distribution Feeder / Substation Application:**

- Size, building blocks, Scalable: Capital Cost to build storage device
    - Distribution Feeder: 50kW / 2 to 8 hours of discharge
    - Substation: 1-10 MWs / 2 to 8 hours of discharge
- Fully integrated system with PCS & controls
- Capital Cost Goal: ~ $ 100 to $150 per kWh total system, and $700 to 1000 per kW, total sys installed (ac to ac)[7]
- Round trip efficiency, ac to ac: 80% or greater
- Recharge time = discharge time divided by efficiency (8 to 10 hours)
- 20 to 30 Year storage system life
- 300 deep cycles per year
- Reliability/Availability > 99%
- O&M cost: fixed $10/kW-yr and variable $10/MWh
- Excellent Power Quality (IEEE 519)
- Fast Transient response
- Easy installation and interconnection
- Easy Siting and Permitting
- UCA / Intelligrid Communication and Control
- Foot Print and space: easy fit within utility distribution area (e.g., pad/substation area
- Modular and Mobile / Transportable
- ISO container / maximum size
- Weight, manageable for ease of installation

Panel 1: Draft Target Specifications: For Storage Application: <u>Renewables – Time Shifting</u>

Utility Renewables – Time Shifting Application:

- Size, <u>building blocks</u>, Scalable: Capital Cost to build storage device
    - Wind: 1- 5 MW / 2 to 8 hours of discharge
    - PV: 2kw to 1MW / 2 to 8 hours of discharge
- Fully integrated system with PCS & controls

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[7] Note these targets are higher than those estimated and reported earlier in this report

- Capital Cost Goal: ~ $ 100 to $150 per kWh total system, and $700 to 1000 per kW, total sys installed (ac to ac)
- Round trip efficiency, ac to ac: 60 to 80% or greater
- Recharge time = discharge time divided by efficiency (8 to 10 hours)
- 20 to 30 Year storage system life
- 300 deep cycles per year
- Reliability/Availability > 99%
- O&M cost: fixed $10/kW-yr and variable $10/MWh
- Excellent Power Quality (IEEE 519)
- Fast Transient response
- Easy installation and interconnection
- Easy Siting and Permitting
- UCA / Intelligrid Communication and Control
- Foot Print and space: easy fit within utility distribution area (e.g., pad/substation area
- Modular and mobile / Transportable
- ISO container / maximum size
- Weight, manageable for ease of installation

Panel 1: Draft Target Specifications: For Storage Application: Renewables – Power Smoothing

- Size, building blocks, Scalable: Capital Cost to build storage device
    - Wind: 1 to 5 MW / 1 to 10 minutes of discharge
- Fully integrated system with PCS & controls
- Capital Cost Goal: ~ $200 to $500 per kW, total sys installed (ac to ac)
- Round trip efficiency, ac to ac: 60 to 80% or greater
- Recharge time = discharge time divided by efficiency
- 20 to 30 Year storage system life
- 1,000 to 10,000 cycles per year
- Reliability/Availability > 99%
- O&M cost: fixed $10/kW-yr and variable $10/MWh
- Excellent Power Quality (IEEE 519)
- Fast Transient response
- Easy installation and interconnection
- Easy Siting and Permitting
- UCA / Intelligrid Communication and Control
- Foot Print and space: easy fit within utility distribution area (eg, pad/substation area
- Modular and mobile / Transportable
- ISO container / maximum size
- Weight, manageable for ease of installation

Panel 2: LOAD MANAGEMENT/PEAK SHAVING/ (DEMAND RESPONSE)
Applications Requirements/ Technical Specifications at the T&D level

a) residential/commercial applications

- Scale: < 50 kW/4 hr (2 kW for 4 hr for large segment)
- IRR or payback time: 3 years

- Small size (wall-mount)
- Maintenance-free
- Power electronics (Possible recharge from renewable)
- consistent with DR (demand response) protocol
- Safety
- Customer or utility control
- Technical issues: #1 Cost
- Possible future options NiMH; Li ion;
- Installed cost target ~ $1,500

b) Industrial/substation/feeder applications

- Scale: > MW/ 4-5 hr
- IRR or payback time 13%, 5 years
- First cost
- System life (23 year utility norm!)
- System efficiency. w/transformer and power conditioner losses
- Footprint
- Transportable
- Safety
- Flow, NaS, Li ion, metal-air, carbon-air, Na/N: cl2
- <<$500/kWh required (installed complete)

Innovation in Systems Integration

The key objective is to advance innovation in the development of turnkey, integrated DESS which meet the prioritized target specifications which a utility can apply, use and install at minimal cost. In this session of the workshop the objective was to identify the critical scientific and technical & integration challenges to be met in achieving our systems goal. The participants identified the following areas of need:

- What can be done to reduce balance of plant costs? Need more specific on key cost drivers in the BOP area.
- List the system integrators
- Look to how Data center system integrators
- Modularity – making modules play together in the simplest way possible. Key challenge is systems control
- Integration of the inverter

- Learn from other industries (e.g. certain fuel cell vendors like Rolls Royce, Delphi, FuelCell Energy, UTC Power and others)
- Design for low cost, high volume manufacturing
- Build into the “box” the things needed to hook into the electric enterprise. A system of systems.
- Improve interface with grid and integrate into the grid design, planning and operations
- Simulations of integrated systems on the grid may be needed.
- Look at international developments; what are they doing in the area of grid integration?

- When you take storage to the home level, (home builders association) and related smart monitoring; smart house concept; with or w/o PV;
- Partnering needed between various stakeholders
- Glavin Initiative – look into work done on energy storage integration
- Integrating supply and demand - Can EPRI help identify early markets for improved integrated systems?

Draft Technology Challenges:

- Flow battery
  - Improve Foot print/energy density, and improve packaging of integrated system
    - Optimize footprint with form factor for site.
    - Double the energy density
  - Reduce Permitting issues
  - Reduce cost/kWh per cycle (capital, operating and maintenance costs, over 20 yrs)
  - Incorporate into design
    - Thermal management
    - Trade-off of electrolyte concentration with surface area of electrodes
- Li-ion
  - Improved electrolyte
  - Improved anode and cathodes
  - Reduce content of cobalt and graphite
  - Improve safety
  - Scale-up

- NAS battery (note: it has about 2.4/kWh/CF)
  - Lower cost of chrome plating of inside of battery can; and/or go from aluminum to steel for can
  - Beta alumina tube: improve characteristics
  - Improve cell seal: ceramic to metal bond
- Ultra-capacitors, increasing energy density can be done by
  - Increase surface area/carbon area via developing nano-carbon materials
  - Increase cell voltage (from 2.5 to 3v to twice that)
- SMES: increase temp of superconductor
- CAES
  - Machinery - apply higher temp expansion turbines to CAES (go from 2100F to 2500F)
  - Above ground piping: demo high pressure piping systems for surface CAES DR applications; and reduce cost of piping and potential corrosion of high pressure pipe systems

Action Plan

In the last session of the workshop, the participants provided input into the development of the project action plan. The key inputs to the plan are detailed below:

Scientific

- Nano materials to drive lower cost / power density; inform nano-stakeholders about needs in the energy storage area
- Explore international opportunities and related developments
- Write a piece for Small Times; or other Education / Media outreach

Technical

- Develop a vision of a micro-grid infrastructure and how electric energy storage fits into the grid of future (at least two feeders)
- Demonstrate this vision- check with CERTs / DOE other stakeholders- prepare a functional description; review SCE circuit of the future
- Explore discussions and coordinate with EPRI's PHEV program
- Follow-up with key vendors, and OEMs to develop more specifics on key technical challenges

Business

- Put a value on reliability – check evolving FERC rules
- Explore alliances & public private partnership

Educational

- Build a central clearing house for information on distributed energy storage
- Inform other utility stakeholders about this work including EPRI's Power Delivery & Markets group
- Post case studies of energy storage applications which are available
- Education of regulators about the value of energy storage
- Prepare more information for stakeholders on where this project is going via the "portal" site.

Commercialization

- Roll-up some of the applications identified in this workshop to a specific market solution
- Take this project's information, organize the material and take to larger forum of key stakeholders
- Develop a communication plan for other stakeholders
- Prepare website/portal & virtual community for information transfer

- Take a look at the six key applications, match with the technologies we have today; develop more specific application requirements and scientific/technical needs for each application.
- Use the PV industry model in California as an example of building more critical mass and a public/private partnership that truly has a mission of growing the application, use, and adoption of energy storage in California and other states. Explore development of legal & business model in CA or vision in the area of renewables or smart meter
    - Form a subgroup to work together on this initiative

Next Steps:

Follow-on efforts in this technology innovation project will include exploring how to better leverage advances and R&D investments in Li-ion battery and other technologies. This will include development of a collaborative network focused on the Li-ion technology area; development of the key technical challenges and barriers for addressing the electric utility market; and conducting workshops and webcasts with key stakeholders in 2007.

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Printed on recycled paper in the United States of America

1014668

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